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PRIMARY LITHIUM ORGANIC ELECTROLYTE BATTERY BA-5557( )/U.(U)
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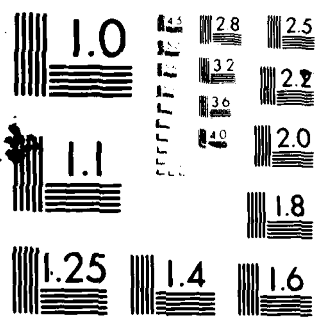

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Research and Development Technical Report

DELET-TR-77-1805-F

PRIMARY LITHIUM ORGANIC ELECTROLYTE BATTERY BA-5557 ( )/U

N. RAMAN

DURACELL INTERNATIONAL INC.
TARRYTOWN, NY 10591

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The BA-5557()/U is a lithium-sulfur dioxide type battery especially designed for constant power devices; this 30-volt battery has a Li/SO_2 coulombic fuel ratio of approximately 0.9, contains two (2) replaceable 8/10 amp slo-blo fuses and has a capacity of 2.5 Ah at c/4 rate at $70^{o}F$. The battery case consists of a flame retardant ABS material.

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I. Introduction and Summary

This report documents the efforts of the Mallory Battery Company on the design, development, and fabrication of battery type BA-5557( )/U employing hermetically sealed lithium-organic electrolyte sulfur dioxide cells (LO-42SHX) under contract No. DAAB07-77-C-1805 which would meet the appropriate electrical and safety requirements set forth in the technical guidelines. The study included the following:

a. Anode and cathode design and construction, consistent with optimization of power density, capacity, and safety

b. Cell venting provisions

c. Intercell and terminal connections

d. Cell arrangement

e. Fuse mounting method

f. Fuse reliability

g. Battery construction material, non-flammability characteristics

h. Thermal studies

The battery, developed as per original technical guidelines, resulted in violent venting of a few cells during direct use in the DMD (constant power device). ERADCOM made a few changes in the technical guidelines which initiated the re-design of the LO-42SHX cell and battery fuse to meet the new requirements. This report covers both work on initial as well as revised cell and battery design.

II. Li/SO_2 Electrochemical System

The Li/SO_2 electrochemical system consists of a lithium anode, a carbon cathode, an electrolyte composed of liquefied SO_2, a lithium salt, and an organic solvent. Sulfur dioxide is the depolarizer.

During discharge, the cell reactions involve the anodic dissolution of Li to Li^+ and the cathodic reduction of SO_2 to $Li_2S_2O_4$ (lithium dithionite) which precipitates within the porous carbon cathode.

$$2Li = 2Li^+ + 2e^- \qquad \text{(Anode reaction)}$$
$$2SO_2 + 2e^- = S_2O_4 \qquad \text{(Cathode reaction)}$$
$$2Li + 2SO_2 = Li_2S_2O_4 \qquad \text{(Overall reaction)}$$

Theoretically, one ampere-hour of capacity is delivered by 0.2589 gm of lithium and 2.4 gm of SO_2.

III. Initial Cell Design and Fabrication

This section covers the feasibility demonstration and preliminary battery design aspects. Fifty (50) LO-42SHX cells were forwarded to ERADCOM in accordance with CLIN 0001 in addition to the forty-nine (49) cells tested under the specified physical, environmental, electrical, and safety requirements. Technical guideline dated 20 November, 1976, was followed in this part of the program.

Initial Cell Design: During the initial stage of the contract, Mallory exerted its major effort to meet specifications established in the original technical guidelines. Cell type LO-42SHX was designed.

The discharge test consisted of a continuous background current of 0.018A, with pulses of 2.8A for 10 ms duration every second, and one pulse of 1.0A for 150 seconds every half hour. This cycle was repeated until voltage reached 1.5 volts. The current load was repeated until voltage reached 1.5. The current load profile is illustrated in Figure 1. The total required capacity at 75°F is 3.048 AH in accordance with the technical guideline dated 20 November, 1976.

The 2.8 and 1.0 amp pulses required a high rate design with maximum electrode surface area. The internal volume is a design constraint since only 13.6 cc are available to accommodate the anode, cathode, separator, and electrolyte, and to allow for electrolyte expansion. A stoichiometrically balanced cell having this internal volume is estimated to deliver 2.5AH, at 75°F at a 24 hour discharge rate.

Experimental cells were fabricated using stoichiometrically balanced and unbalanced amounts of lithium and SO_2. The balanced cell design utilized .006" thick lithium foil, resulting in a theoretical $Li:SO_2$ capacity ratio of approximately 1:1. The unbalanced cell had excess lithium (.008" thick) resulting in a theoretical $Li:SO_2$ capacity ratio of approximately 1.2:1.0. The designs were as follows:

1. Balanced Cells:

Lithium: 22" x .700" x .006" Theoretical anode capacity = 3.12 AH

Cathode: 24.5" x .700" x .024"

Electrolyte: 10.8 ± .2 grams Theoretical SO_2 capacity = 3.15 AH

Li:SO_2 Theoretical Capacity Ratio = 1.0:1.0

Anode current density at 2.8A pulse = 14.0 mA/cm^2

2. Unbalanced Cells:

Lithium: 20" x .700" x .008" Theoretical anode capacity = 3.76AH

Cathode: 22.5" x .700" x .024"

Electrolyte: 10.8 ± .2 grams Theoretical SO_2 capacity = 3.15 AH

Li:SO_2 Theoretical Capacity Ratio: 1.19:1.00

Anode current density at 2.8A pulse = 15.5 mA/cm^2

In the above designs, the electrode widths were maximum for the cell height. Thus, the geometric area may be increased only by increasing the electrode lengths and reducing the thickness. An anode thinner than .006" was not considered, mainly due to its high cost and low percent utilization.

Balanced and unbalanced cells delivered equal capacities at -40°F, whereas at 70°F the capacity of the balanced cell was slightly greater. In general, the unbalanced cells deliver more capacity than the balanced cells at 70°F and low current density levels (up to 6 mA/cm^2), whereas at high current density levels, balanced cells are slightly superior. It may be concluded that the capacity is rate limited, and thus the balanced cells, having greater electrode surface area, delivered slightly more capacity than the unbalanced cells at high rates.

Considering the above test results, the stoichiometrically balanced cell design was selected for battery type BA-5557( )/U.

The cell schematic is illustrated in Figure 2.

Cell Fabrication: Cells are constructed by winding rectangular strips of anode-separator-cathode-separator layers of the appropriate width into a cylindrical composite roll. This is then inserted into the nickel plated steel container. This construction supplied high electrode surface areas to impart high current rate/low temperature capabilities. The anode is electrically connected to the steel container. The cathode terminal is electrically connected to the central metal post of the glass-to-metal seal. The top is then hermetically sealed in place by welding the periphery to the can. Electrolyte is subsequently dispensed through the fill tube in the can bottom. The fill tube is then hermetically sealed by welding.

The negative electrode (anode) is a continuous strip of lithium ribbon which serves both as the active electrode and the current collector. The positive electrode (cathode) consists of a carbonaceous mixture deposited upon and within a current collector (expanded aluminum grid). The cathode mix is composed of carbon and teflon (suspension). The cathode is electrically attached (welded) to the positive metal post via a pure aluminum tab which is located at the end of the electrode at the center of the cylindrical composite roll.

The separator is microporous polypropylene. Both length and width are adjusted to adequately cover both electrode surfaces.

The electrolyte contains approximately 70% by weight sulfur dioxide (depolarizer). The remaining 30% consists of the additive conductive salt (LiBr) and an organic solvent.

Hermetic Seal Design: Based upon prototype cell designs constructed both at Mallory Corporate Laboratory for Physical Science and at the Mallory Battery Company, a glass-to-metal insulated feed through and cell top closure has been developed. This is being used in all hermetic cell designs. The basic construction is shown in Figure 3. It consists of a glass seal, a solid post/positive terminal, and an eyelet.

The metal of the solid post must be compatible with the corrosive electrolyte while being maintained at a 3 volt positive potential with respect to lithium.

A tantalum feed through of 0.125" diameter is used in the cell design. Tantalum forms an excellent glass-to-metal seal.

The flange of the eyelet around the glass seal is welded to the surrounding nickel plated steel cell top. The solid metal post in the glass seal serves as the external positive electrical terminal of the cell.

After insertion of the rolled electrode-separator assembly and welding of the positive and negative tabs to the solid post and can, the periphery of the top assembly is then welded to the edge of the steel container.

An epoxy resin fill is applied around the solid post and in the surrounding area on the top assembly to provide mechanical integrity.

Cell Venting Mechanism: The principle of the integral vent design is illustrated in Figure 4. It involves a pressure sensitive venting container. Two diametrically opposed convolutions (A) are connected by two narrow bridges (C-C) where the can thickness has been reduced by approximately 50% of its original thickness. As the internal cell pressure increases, the area confined by the convolutions moves outward, causing the convolutions to unfold. However, the thinner material cross section at the bridges leads to a tearing action which results in mechanical rupture.

The shape and width of the bridge band determines the venting parameters. The action can be varied controllably from a slow, pressure release to an abrupt opening of a substantial vent area. Our experience shows that venting can be reproducibly obtained in a pressure range from 350-500 p.s.i.g. using this proposed vent concept.

Cells were fabricated by the Mallory Battery Company and shipped to ERADCOM for tests in accordance with CLIN 0001.

All finished cells are checked for O.C.V. (2.915-3.05 volts) and load voltage (2.1 volts within 5 seconds at a 3 amp load at 75°F for cell type LO-42SHX) prior to releasing the cells for shipment, testing, or battery fabrication.

Fifty (50) cells were shipped to ERADCOM in November, 1977, and fifty (50) additional cells of the same type were tested at Mallory in accordance with CLIN 0001.

These cells had poor start-ups, the unsatisfactory performance being attributed to the cathode. Manufacturing had a cathode fabrication problem, which has since been corrected.

ERADCOM was accordingly sent forty-nine (49) additional cells in May, 1978, and forty-nine (49) additional cells were tested at Mallory.

IV. Cell Testing, Results and Analyses on Initial Design

Cells were tested in accordance with the technical guidelines for Battery BA-5557( )/U dated 20. November, 1976. The tests were carried out by the Quality Control Department, and the pertinent data sheets are included in the Appendix.

1. Environmental Tests

Fifty (50) cells were subjected to environmental tests: temperature shock, shock, vibration, and altitude. There was no visual evidence of physical damage or leakage as a result of these tests, nor was there any significant change in O.C.V. The shock, vibration, and bounce tests were carried out by Stanford Technology Corporation, Glenbrook, Connecticut.

2. High Temperature Storage Tests

After the above environmental tests were completed, the cells were stored at 160°F for one month. Cell weights were taken before and after the high temperature storage. The average weight loss was 0.0083 grams per cell. Part of this weight loss may be attributed to weight lost by the epoxy on the cell tops. Separate studies have revealed a 0.37% weight loss by epoxy after storage at 160°F for one month. Since no visual leaks were detected, the remainder of the weight loss may be attributed to weighing technique and to cosmetic changes on the cells.

3. Electrical Tests

After 30 days storage at 160°F, the 50 cells were discharged. It was found that the cells had poor start-ups at -40°F, and the capacities delivered were lower than expected. This unsatisfactory performance was attributed to a cathode problem, which was later resolved. Similar problems were encountered in other cell types with respect to start-up capacity after 30 days storage at 160°F.

Ninety-eight (98) additional cells were fabricated, forty-nine (49) of which were shipped to ERADCOM. The remaining 49 cells were subjected to electrical tests after 15 days of storage at 160°F. The environmental and 30 day storage tests were waived by ERADCOM, since the previous batch of cells was subjected to the same. The electrical tests were carried out in accordance with the technical guidelines dated 20, November, 1976.

Ten (10) cells each were discharged with the pulse load at 70°, -40°, 130°, and 160°F. The data sheets are included in the Appendix, and the test results are summarized in Table III.

The operating voltages at the pulse loads are illustrated in Figures 5, 6, and 7 for discharges at 70°, 130°, and -40°F, respectively.

The operating capacities delivered by the cells were 2.04, 1.83, 1.69, and 0.92 AH at 70°, 130°, 160°, and -40°F, respectively. The required capacity at 70°, 130°, and 160°F is 3.048 AH and that at -40°F is 1.524 AH.

Under the pulsing regime, the average capacities delivered at 130°, 160°, and -40°F are 90, 83, and 45% respectively, of that at 70°F. These results are in agreement with similar observations made on other Li/SO_2 cells.

The average cell capacities under pulsing were lower than those required in the technical guidelines. In general, there are certain discharge parameters that affect cell capacity, such as discharge rate, constant current discharge versus a resistor, high temperature storage, etc. Additional cells were, therefore, discharged at 70° and -40°F to study the effect of some of these parameters on cell capacity.

The following additional discharge tests were carried out:

a. Ten (10) cells at 70° and -40° under constant 1.25 amp load after three (3) days storage at 160°F.

b. Ten (10) cells at 70° and -40°F under constant 1.25 amp load after 15 days storage at 160°F.

c. Nine (9) cells at 70°, and -40°, under continuous 2.25 ohm load after 15 days storage at 160°F.

The test results are illustrated in Tables IV and V. The following observations can be made from the test results:

1. At 70°F, 1.25A constant current drain delivered approximately equivalent load.

2. Capacity loss of approximately 10% occurred upon cell storage at 160°F for 15 days.

3. Continuous resistive load delivered approximately 4% and 20% more capacity at 70°F and -40°F, respectively, then at approximately equivalent current load.

From the above observations, it may be concluded that 15 days storage at 160°F and the pulse load caused a significant reduction in cell capacity. Thus under the pulse load, although the capacities delivered were lower than required, they were in agreement with the discharge characteristics as determined above.

Safety Test:

Nine (9) cells stored at 160°F for 15 days were force discharged by placing each cell in series with a power supply and discharging it at 0.5 amps for 16 hours or until venting occurred. The cells reached an average maximum temperature of 155°F, the range being 134.4° to 178.1°F. The cells ran for an average of 4.5 hours to 1.5 volts, delivering 2.25AH. None of the cells vented, exploded, or caught fire, thus complying with the safety requirement. The data is included in the appendix. The cell voltage and temperature versus time profile is typically illustrated in Figure 8. The cell reached a maximum temperature at the time the voltage was most negative. Upon continuing the forced discharge, the cell voltage stabilized at -3.6 volts and the cell temperature stabilized at 135°F.

It may thus be concluded that the high current rate cell, type LO-42SHX was designed and tested for the lithium organic electrolyte battery, BA-5557( )/U.

At the pulse discharge load, the capacities of cells after 15 days storage at 160°F were 2.04, 1.83, 1.69, and 0.92 AH at 70°

130°, 160°, and -40°F, respectively. These are somewhat lower than the required capacities specified in the technical guidelines. Lower values were observed for the following reasons:

1. Degradation of capacity due to storage at 160°F.

2. Reduction of capacity due to the high drain rate utilization of a pulsing regime involving constant currents.

The stoichiometrically balanced cell design (Li:SO_2 capacity ratio = 1) has been verified to be safer than the unbalanced cell design. Cells force discharged at .5A with an external power supply for 16 hours did not vent, explode, or catch fire, which is in compliance with the technical guidelines.

V. Preliminary Battery Design:

The battery design is illustrated in figure 9. It utilizes ten (10) LO-42SHX cells with two series strings of five (5) cells each connected to the socket as shown. Two replaceable three amp slo-blo fuses were provided for safety in the event of an external short circuit. The ten (10) cells were adhesive bonded to the case and cover which were made from flame retardant ABS material.

A few problems were encountered in meeting battery dimensional requirements. First, the battery case as received from the supplier was out of spec. dimensionally. Then during fabrication, misalignment of the battery case and cover resulted in further increases in dimensions. Then vent washers on the cells were also slightly non-concentric with the cells. This bulged the case and cover at certain spots. The resulting battery dimensions were between .015" and .025" over the specified maximum. The fabricated batteries were mechanically reworked to comply with dimensional requirements.

Precision molding of the battery case and the cover is difficult due to the intrinsic material characteristics of flame retardant ABS. Mallory, therefore, requested that ERADCOM consider changing the dimensional specifications of the battery as follows:

	IS	REQUEST CHANGE TO	APPROVED
Thickness	1.438 ± .030"	1.460 ± .030"	1.438 ± .040"
Height	3.910 ± .030"	3.925 ± .030"	3.910 ± .030"
Width	4.126 ± .030"	4.141 ± .030"	4.124 ± .060"

The preliminary battery design and cell fabrication report was sent to ERADCOM for approval of the cell design, and Mallory was advised by way of a letter from the contracting officer to the Mallory Project Engineer, to fabricate 170 batteries.

One-hundred seventy (170) batteries, type BA-5557( )/U were fabricated in accordance with CLIN 0002. One-hundred fifty (150) of these were shipped to ERADCOM whereas twenty (20) batteries were scheduled to be tested by Mallory.

These twenty (20) batteries were subjected to environmental testing. The shock and vibration tests were conducted by Stamford Technology Corporation, Glenbrook, Connecticut. The temperature and altitude tests were carried out by the Quality Control Department, Mallory Battery Company. There was no visual evidence of physical damage or leakage as a result of these tests. There was no significant change in open circuit voltage. The data is included in the Appendix.

While the twenty (20) batteries were being prepared for tests by Mallory for electrical performance, ERADCOM reported that their preliminary test of BA-5557 in DMD, constant power input device, resulted in a problem when violent venting of some battery cells occurred near the termination of battery life. At this stage, all tests to be done by Mallory were stopped. A meeting was scheduled between Mallory and ERADCOM to discuss this problem. It was realized at that time that the requirement for DMD is slightly different from the original set of technical guidelines for BA-5557( )/U.

The DMD, being a nearly constant power device (17-22) watts, will proportionately increase its current requirements if and when the proper voltage decreases. For example, if the DMD operating battery voltage versus time discharge curve profile can be described as having a fairly flat voltage plateau of constant current discharge until near the end of life or 90% utilization of its coulombic capacity (2AH). At this time the DMD's operational voltage becomes transistory and drops rapidly to 20 volts resulting in a current of 1.07A when powered by a BA-5557 battery. Subsequent battery discharge with DMD results in intervals of decreased voltage which depend upon when and how many cells (ten wired series) become depleted of coulombic capacity. During these cell depletion events, the DMD current requirements will proportionately increase thus forcing the terminal battery voltage to zero. The maximum current obtained while powering the DMD approaches 1.35A at 13 volts. The DMD, however, loses illumination of the read-out screen below 16 volts and 1.25A. The high current rated Slo-blo fuse does not prevent the subsequent venting of the first battery-depleted cell which becomes overheated (200°F) when it is current driven by the remaining nine (9) cells into voltage reversal.

Mallory and ERADCOM both investigated the force discharges of individual LO-42SHX cells used in BA-5557 through zero volt into voltage reversal at currents ranging from 0.6 to 2 amperes.

Three (3) batteries from the lot shipped to ERADCOM were tested for cell venting by short circuiting the battery after bypassing the fuse. The heat generated was due to short circuiting the battery. The battery material did not catch on fire, and the cells vented safely without any explosion or fire.

A few cells taken from the same lot of batteries were force discharged at 1.2 and 1.5 amperes (70°F) for 4.5 hours continuously, and the results are illustrated in Table VI. All cells were insulated during the test. No cell explosion or fire was experienced.

Four (4) cells from the same lot of batteries were force discharged at 600mA at 70°F for approximately 6.5 hours. Results are illustrated in Figure 10. The minimum cell voltage was -6.63V and the maximum cell temperature was 149°F. None of the cells vented, exploded, or caught fire. At the end, the cell temperature and voltage were stabilized at 128°F and -2.5 volts, respectively. A battery was also force discharged at 600 mA at 70°F for 6.5 hours continuously. Here again, there was no safety problem, and the minimum voltage was -34V and stabilized at -22.0 volts (see figure 11).

Another cell from the same lot was force discharged at 0.6A at 70°F for 6.5 hours continuously, then at 1.8A for 1.8 hours and 2.5A for 0.1 hour. Results are illustrated in figure 12. Here again, there was no safety problem except that the cell vented normally.

Work was continued to duplicate ERADCOM results. Duplication of the results were accomplished only when some batteries and cells were force discharged at 1.25 amperes and while the cell/battery was in voltage reversal.

Two (2) cell designs, type A and B, were considered for safety and capacity evaluation. See Table VII for program detail.

DESIGN A

Lithium Anode: 22" x 0.700" x .006"

Theoretical Capacity: 3.12 AH
Three (3) nickel tabs welded to lithium anode.

Carbon Cathode: 24.5" x 0.700" x 0.24"
Coulombic Capacity: 4.25 AH

Electrolyte: 10.8 ± .2 grams, 70% SO_2 by weight. Theoretical capacity of SO_2 = 3.15 AH

DESIGN B

Lithium Anode: 20" x .700" x .006"
Theoretical Capacity: 2.84 AH
Three (3) nickel tabs welded to lithium anode.

Carbon Cathode: 22.5" x 0.700" x .024"
Coulombic Capacity: 3.90 AH

Electrolyte: 11.5 ± .2 grams, 70% SO_2 by weight. Theoretical SO_2 capacity = 3.35 AH

Li/SO_2 Capacity Ratio: 0.85:1.00

Design A was identical to the original design except for the anode which had multiple tabs to improve its efficiency of utilization. Design B was an improved version of Design A with respect to Li/SO_2 ratio.

Nearly 30 cells were made from each design. Weight of anode, cathode, and electrolyte were individually monitored for each cell. Cells from each group were tested for capacity by discharging @ 650 ma three different temperatures, -40°F, 70°F, and 130°F. Both component information and cell discharge data of Design A and B are tabulated in Tables VIII and IX respectively. As shown in the tables, there was insignificant differences in capacity between both groups. Even cell temperature during discharge did not show any appreciable difference between these groups. Both designs delivered approximately 2.5 AH at 70°F and 130°F and 0.7 AH at -40°F. Figures 14 and 15 detail 1.4A constant current discharge continuously for 3.5 hours. Here again, there was no difference between these two groups. In both cases, the time to zero volts, the time to deep voltage reversal, and the maximum cell temperature were almost the same. Table X and XI, as well as figures 19 and 20 illustrate forced discharge @ 70°F @ 1.4A for 3.5 hours of group A and B, respectively. None of the cells vented.

Based on the above data, it is clear that both designs are considered safe and acceptable regarding new technical guidelines. ERADCOM selected Design B because of its higher SO_2/Li ratio.

Twenty (20) batteries were fabricated based on cell Design B. Fifteen (15) of these modified BA-5557( )/U batteries were shipped to ERADCOM in accordance with CLIN0006, modification P0002. The remaining five (5) batteries were force discharged at 1.4A constant current for 3.5 hours continously at 70°F. Fuses in the batteries were bypassed during the test. None of the batteries exploded or caught fire. The battery cases deformed slightly, however, opening at the seam up to .036".

VI CONCLUSIONS AND RECOMMENDATIONS

High current rate cell, type LO-42SHX, was designed and tested for lithium organic electrolyte battery, BA-5557( )/U.

The battery, type BA-5557( )/U consisted of ten (10) LO-42SHX cells with two (2) replaceable 8/10 amp slo-blo fuses. The battery case and cover were made from flame retardant ABS material.

The cells and batteries were subjected to the environmental tests - thermal shock, shock, vibration, and altitude tests. There was no visual evidence of physical damage or leakage as a result of these tests, nor was there any significant change in OCV.

Cells and batteries were force discharged at 1.4A for 3.5 hours at 70°F. No explosion, fire, or unsafe situation resulted.

The cells delivered 2.57, 2.56, and 0.71 AH at 0.65A drain to 2.0V at 70°, 130°, and -40°F, respectively. The cells met all the capacity requirements in accordance with paragraph 2.4.4 of the revised technical guidelines dated 20, November, 1978.

Degradation in capacity after elevated temperature storage was mainly attributed to glass seal corrosion. Mallory developed a protective coating for the glass on a prior project at its own expense, which would take care of this glass corrosion problem.

Design B is better than Design A in regards to Li/SO_2 ratio. In other words, the excess electrolyte in cell Design B helps in compensating for production variability with respect to lithium weight, electrolyte weight, and percentage of SO_2 in the electrolyte.

Three (3) tabs on the lithium anode did help in improving the utilization of the anode during discharge, but this is not practical from a production standpoint. Mallory developed in a parallel project and at its own expense, a new technique for improving the continuity of anodes which call for thinner lithium. A longitudinal "reaction barrier" on the separator has been introduced, which allows for a continuous lithium strip at the center of the electrode to the end of cell life. This barrier should increase anode efficiency nearly equivalent to the multiple tabbing technique.

One of the areas investigated before improving the Li/SO_2 ratio, was the cathode. The average current of the BA-5557( )/U battery is under 1 mA/cm^2. The attached graph (fig. 13) provides the ampere hour/gram of carbon at various rates at 70°F. As shown if fig. 13, the LO-42SHX cathode has more than enough carbon to support the cell's coulombic capacity of sulfur dioxide.

Although these cells meet the specifications of the present technical guidelines for the primary lithium organic electrolyte battery, BA-5557()U, dated 20, November, 1976, some modifications must be made in the cell/battery or both for safe operation with DMD.

Based on ERADCOM and Mallory investigations, the following conclusions were drawn:

a. The battery fuse should be changed from 3 amp Slo-blo to 8/10 Amp Slo-blo. This may prevent cells from venting violently during discharge with DMD since these fuses blow at 1.00 to 1.08A within several minutes.

b. Introduce multiple tabs on lithium anode to improve the efficiency of anode utilization during discharge.

c. Evaluate a new design with reduced lithium/SO_2 ratio and also with multiple tabs on anode.

The test program used is outlined in Table VII.

Acknowledgement

Helpful suggestions from John Christopulos of ERADCOM are gratefully acknowledged.

TABLE I

Preliminary Tests on Balanced Cells (Li:SO_2 = 1:1)

Cell #	Test Type	Load	Test Temp. °F.	Results and Comments
13 14 15 16	Safety: Drive cells with power supply for eight (8) hours	.75A .75A .75A .75A	-20 -20 -20 -20	No venting or explosion. Maximum cell temp. 100°F.
17 18	capacity capacity	pulse load in accordance with technical quidelines	70 70	19.5 hours to 1.5V, equivalent cap. = 2.48 AH
19 20	capacity capacity		-40 -40	5 hours to 1.5V, equivalent cap. = .63 AH

TABLE II

Preliminary Tests on Unbalanced Cells ($Li:SO_2$ = 1.19:1)

Cell #	Test Type	Load	Test Temp. °F.	Results and Comments
	Safety:			
1	Drive cells	.75A	-20	Violent venting.
2	with power supply for eight (8)	.75A	-20	Explosion, bottom blown off, max. cell temp. 323°F.
3	hours	.75A	-20	Explosion, fire, max. cell temp. 357°F.
4		.75A	-20	Explosion, fire, max. cell temp. 325°F.
5	capacity	Pulse load in accordance with Technical Guidelines	70	18 hours to 1.5V
6	capacity		70	17 hours to 1.5V
7	capacity		-40	6 hours to 1.5 V
8	capacity		-40	4.5 hours to 1.5V
9	capcity		70	16.5 hours to 1.5V
10	capacity		70	17.75 hours to 1.5V
11	capacity		-40	6.5 hours to 1.5V
12	capacity		-40	4 hours to 1.5V

TABLE III

Pulse Load Discharge Tests After 15 Days Storage at 160°F

Cell #	Discharge Temp. °F	O.C.V.	Hours To 1.5V	Hours To 0.0V	Capacity AH	Cell Temp. Range °F	Start-Up Seconds
10	70	3.004	15.04	15.04	1.910		
11	70	3.006	18.88	19.00	2.398		
12	70	3.009	14.0	17.6	1.778		
13	70	3.007	16.0	16.0	2.032		
14	70	3.003	16.0	16.0	2.032		
15	70	3.005	16.5	16.5	2.096		
16	70	3.006	17.1	18.0	2.172		
17	70	3.003	17.5	17.5	2.223		
18	70	3.010	14.5	14.5	1.842		
19	70	3.006	15.4	15.5	1.969		
20	130	3.009	15.5	16.0	2.032	130 to 145	
21	130	3.015	13.1	13.1	1.664	130 to 145	
22	130	3.014	15.0	16.0	2.032	130 to 145	
23	130	3.008	14.7	14.7	1.867	130 to 145	
24	130	3.004	14.5	15.5	1.969	130 to 145	
25	130	3.003	13.0	13.0	1.651	130 to 145	
26	130	3.007	13.5	13.5	1.715	130 to 145	
27	130	3.003	14.3	14.3	1.816	130 to 145	
28	130	3.007	15.0	15.0	2.032	130 to 145	
29	130	2.996	15.5	16.0	2.032	130 to 145	
30	160	3.006	13.0	13.0	1.651	160 to 175	
31	160	3.008	13.5	13.5	1.715	160 to 175	
32	160	3.004	13.5	14.3	1.816	160 to 175	
33	160	3.006	12.5	12.9	1.638	160 to 175	
34	160	3.005	13.0	13.5	1.715	160 to 175	
35	160	3.004	14.0	14.0	1.778	160 to 175	
36	160	2.998	13.4	13.5	1.702	160 to 175	
37	160	3.012	13.5	14.8	1.715	160 to 175	
38	160	3.004	13.5	14.5	1.715	160 to 175	
39	160	3.006	13.5	15.0	1.715	160 to 175	
40	-40	3.003	6.5	12.3	.826	-40 to -25	43
41	-40	3.012	7.5	11.5	.953	-40 to -25	77
42	-40	3.005	7.0	12.8	.889	-40 to -25	355
43	-40	3.007	7.0	12.1	.889	-40 to -25	197
44	-40	3.016	7.9	12.5	1.003	-40 to -25	137
45	-40	3.013	7.8	11.5	.991	-40 to -25	1,169
46	-40	3.014	7.0	12.5	.889	-40 to -25	-----
47	-40	3.016	7.5	12.2	.953	-40 to -25	-----
48	-40	2.997	---	----	-----	-40	-----
49	-40	3.015	7.0	11.7	.889	-40 to -26	457

TABLE IV

Discharge Tests with 1.25A Drain

O.C.V.	Discharge Temp. °F	Hours To 1.5V	Capacity AH	Storage At 160°F Prior To Discharge
2.945	-40	.783	.98	3 days
2.948	-40	.717	.89	3 days
2.946	-40	.767	.96	3 days
2.956	-40	.833	1.04	3 days
2.945	-40	.800	1.00	3 days
2.97	70	1.92	2.40	3 days
2.98	70	2.08	2.60	3 days
2.99	70	2.11	2.64	3 days
2.98	70	2.11	2.64	3 days
3.00	70	2.0	2.50	3 days
3.02	-40	.57	.71	15 days
3.02	-40	.65	.81	15 days
3.03	-40	.83	1.03	15 days
3.03	-40	.63	.79	15 days
3.04	-40	.84	1.05	15 days
3.03	70	2.07	2.58	15 days
3.02	70	1.73	2.17	15 days
3.03	70	1.58	1.98	15 days
3.03	70	2.1	2.63	15 days
3.03	70	2.07	2.58	15 days

TABLE V

Discharge Tests with 2.25Ω Continuous
After 15 Days Storage at 160°F

O.C.V.	Discharge Temp. °F	Hours To 1.5V	Capacity AH
3.03	70	2.07	2.44
3.02	70	2.05	2.42
3.03	70	1.93	2.28
3.02	70	2.23	2.63
3.03	70	2.23	2.63
3.03	-40	1.28	1.14
3.03	-40	1.28	1.14
3.02	-40	1.30	1.16
3.03	-40	1.32	1.17

TABLE VI

LO-42SHX CELL TESTING

CELL #	CELL CODE	CC LOAD AMPS	OCV	TIME VERSUS CELL VOLTAGE/CELL BODY TEMPERATURE									REMARKS
1	780822	1.2	-	2Hrs 9Min 1.5V 129.9°F	2Hrs 12' 0V 139°F	2Hrs 15' -14.788 195.3°F	2Hrs 15'9" 200.4°F -5.066V	2Hrs 30' -1.238V 188.3°F	3Hrs 4' -1.37V 165.9°F	3Hrs 30' 1.505V 168.9°F	4Hrs 4' -1.16V 158.7°F	4Hrs 30' 1.067V 150°F	No Vent
2	780822	1.2	-	2Hrs 12' 1.5V 132°F	2Hrs 23' 0V 141°F	2Hrs 30' -3.123V 214°F	2Hrs 34' -1.837V 256°F		3Hrs 4' -2.49V 193.9°F	3Hrs 30' -2.423V 189.1°F	4Hrs 4' -2.369V 186.3°F	4Hrs 30' -2.328V 184.7°F	Cell Vented Normal
3 CELL WAS TAKEN FROM ECOM BATTERY WHICH WAS DIS-CHARGED	780621	1.2	2.943	19' 47" 1.5V 104.1°F	22' 37" 1.996V 109.3°F	41' 15" -3.249V 164.2°F	1Hr 13' -2.504V 184.2°F	2Hrs 30' -1.635V 157.4°F	3Hrs 4' -1.78V 161.8°F	3Hrs 30' -1.75V 159.3°F	4Hrs 4' -1.668V 158.1°F	4Hrs 30' -1.698V 159.3°F	No Vent
4	" "	1.2	2.946	5' 42" 2.568V 91.2°F	13' 0" -3.107V 113.2°F	16' 10" -4.109V 151.3°F	41' 15" -2.3V 119.1°F	2Hrs 30' -1.944V 165.8°F	3Hrs 4' -1.868V 163.8°F	3Hrs 30' -1.851V 162.5°F	4Hrs 4' -1.882V 163.2°F	4Hrs 30' -1.798V 161.1°F	No Vent
5	" "	1.5	0.434	0Hr 0'7" -6.738V 91.2°F			25' 17" -3.969V 272°F	2Hrs 30' -3.821V 272.6°F	3Hrs 4' -3.815V 273.9°F	3Hrs 30' -3.605V 267.1°F	4Hrs 4' -3.341V 257.3°F	4Hrs 30' -2.857V 283.3°F	CELL VENTED NORMAL
6	780822	1.5	2.959	1Hr 43' 1.5V	1Hr 46' 0V	1Hr 50' -3.295V		2Hrs 30' -2.677V	3Hrs 4' -2.767V	3Hrs 30' -2.786V	4Hrs 4' -2.804V	4Hrs 30' -2.815V	CELL VENTED NORMAL

TABLE VII

BA-5557 TEST PROGRAM

Tech Guidelines dated 11/20/78

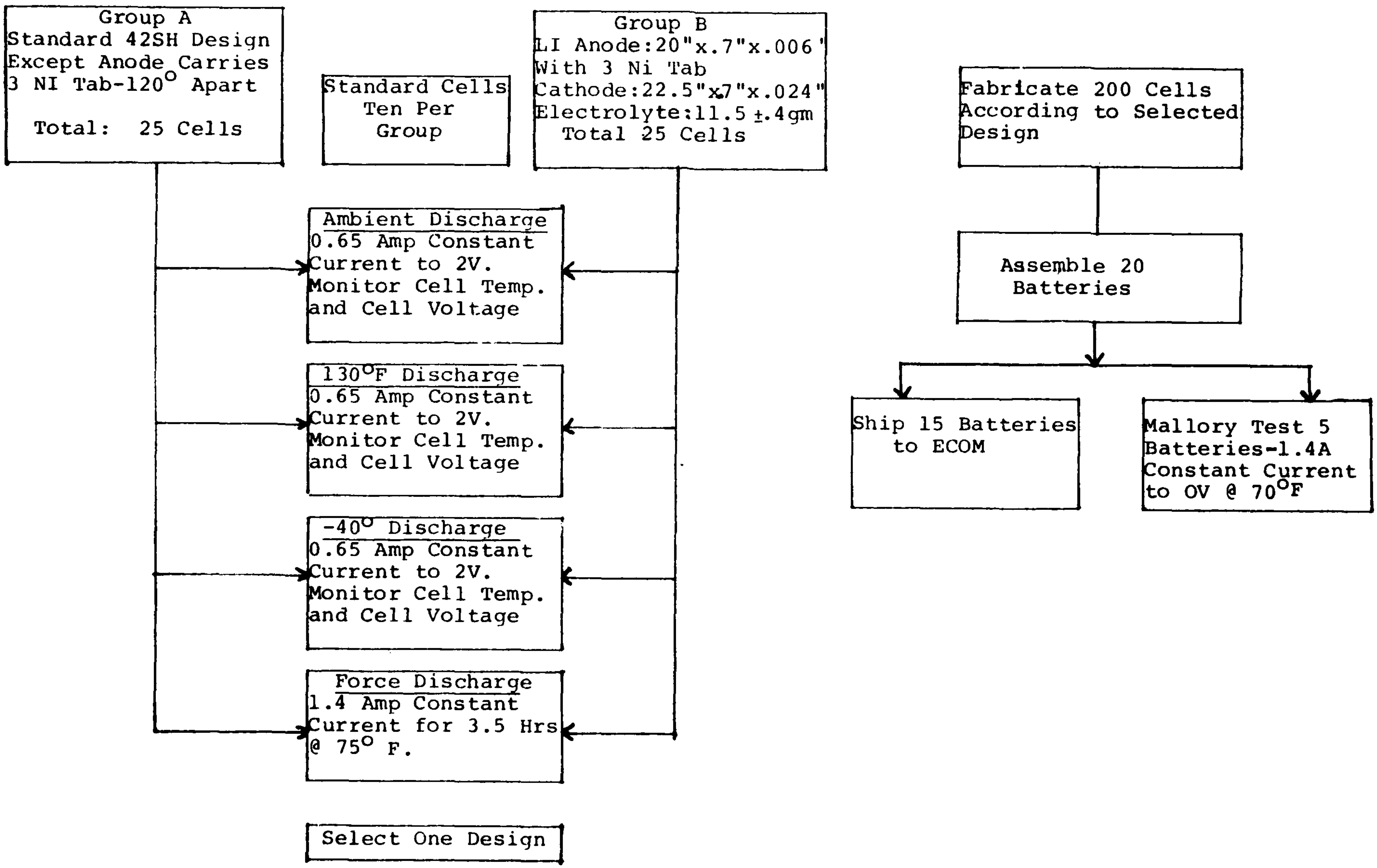


TABLE VIII

EVALUATION OF CELL DESIGN "A"

CELL #	CATHODE THK, IN	CATHODE WT, GM	CARBON WT, GM	MAX CARBON CAPACITY AH	LITHIUM WT, GM	THEOR Li CAP, GM	ELECTROLYTE WT, GM	THEOR SO_2 CAP, AH	SO_2/Li CAPACITY RATIO	SCC AMPS	CAPACITY AH TO 2.0V WITH .65A
1	.026	3.80	2.55	4.32	.814	3.144	10.03	2.93	.932	44	.695 @ -40°F
2	.024	3.65	2.40	4.07	.805	3.109	10.61	3.09	.994	46	
3	.026	3.79	2.54	4.31	.812	3.136	10.17	2.966	.946	45	.748 @ -40°F
4	.026	3.74	2.49	4.22	.806	3.113	10.29	3.00	.964	45	
5	.025	3.76	2.51	4.25	.809	3.125	9.90	2.89	.925	45	.735 @ -40°F
6	.025	3.74	2.49	4.22	.814	3.144	10.53	3.07	.976	47	
7	.026	3.80	2.55	4.32	.807	3.117	11.54	3.36	1.078	45	.800 @ -40°F
8	.026	3.72	2.47	4.19	.811	3.132	10.35	3.02	.964	48	
9	.023	3.69	2.44	4.14	.809	3.125	10.96	3.20	1.024	43	.748 @ -40°F
10	.026	3.74	2.49	4.22	.815	3.150	10.44	3.05	.968	45	2.39 @ 70°F
11	.025	3.71	2.46	4.17	.815	3.150	10.91	3.18	1.009	45	
12	.026	3.84	2.59	4.39	.810	3.127	10.60	3.09	.988	45	
13	.026	3.80	2.55	4.32	.808	3.121	10.82	3.16	1.012	50	2.50 @ 70°F
14	.026	3.80	2.55	4.32	.812	3.136	11.00	3.20	1.020	45	2.68 @130°F
15	.026	3.84	2.59	4.39	.806	3.113	10.89	3.18	1.022	50	2.47 @ 70°F
16	.026	3.73	2.48	4.20	.811	3.132	10.77	3.14	1.002	50	
17	.026	3.75	2.50	4.24	.809	3.125	10.79	3.15	1.008	42	
18	----	----	----	----	----	-----	-----	----	-----	--	------------
19	----	----	----	----	----	-----	-----	----	-----	--	------------
20	.024	3.66	2.41	4.08	.802	3.098	11.17	3.26	1.052	45	2.55 @ 70°F
21	.025	3.75	2.50	4.24	.811	3.132	10.95	3.19	1.018	50	2.63 @ 130°F
22	.024	3.68	2.43	4.12	.803	3.102	10.82	3.16	1.018	50	2.60 @ 130°F
23	.026	3.81	2.56	4.34	.803	3.102	11.01	3.21	1.035	50	2.57 @ 130°F
24	.026	3.78	2.53	4.29	.800	3.090	10.51	3.07	.993	46	
25	.022	3.57	2.32	3.93	.800	3.090	10.93	3.19	1.032	46	2.65 @ 70°F
26	.026	3.79	2.54	4.31	.799	3.086	10.66	3.11	1.008	47	
27	.026	3.74	2.49	4.22	.786	3.036	10.69	3.12	1.028	47	
28	----	----	----	----	----	-----	-----	----	-----	--	------------
29	.026	3.88	2.63	4.46	.788	3.044	10.72	3.13	1.028	45	

TABLE IX

EVALUATION OF CELL DESIGN "B"

CELL #	CATHODE THK, IN	CATHODE WT, GM	CARBON WT, GM	MAX CARBON CAPACITY AH	LITHIUM WT, GM	THEOR Li CAP, AH	ELECTROLYTE WT, GM	THEOR SO_2 CAP, AH	SO_2/Li CAPACITY RATIO	SCC AMPS	CAPACITY AH TO 2.0V WITH .65A
1	.025	3.43	2.28	3.85	.772	2.982	11.35	3.31	1.109	45	2.59 @ 70°F
2	.026	3.46	2.31	3.90	.779	3.086	11.52	3.36	1.117	50	.702@ -40°F
3	.026	3.47	2.32	3.92	.780	3.012	11.66	3.40	1.129	50	
4	.024	3.38	2.23	3.77	.775	2.993	11.42	3.33	1.113	50	
5	.026	3.42	2.27	3.84	.779	3.008	11.51	3.36	1.117	45	
6	.025	3.42	2.27	3.84	.787	3.041	11.49	3.35	1.102	50	2.68 @ 130°F
7	.023	3.33	2.18	3.68	.778	3.005	11.50	3.35	1.115	50	
8	.026	3.47	2.32	3.92	.782	3.020	11.63	3.39	1.123	50	2.61 @ 70°F
9	.026	3.43	2.28	3.85	.782	3.020	11.55	3.37	1.116	50	Vented-Short
10	.026	3.48	2.33	3.94	.782	3.020	11.59	3.38	1.119	50	
11	.024	3.42	2.27	3.84	.774	2.989	11.58	3.38	1.131	50	
12	.025	3.47	2.32	3.92	.770	2.974	11.14	3.25	1.093	45	
13	.025	3.42	2.27	3.84	.782	3.020	11.53	3.36	1.113	45	2.62 @ 130°F
14	.023	3.55	2.40	4.06	.772	2.982	11.55	3.37	1.130	45	2.55 @ 70°F
15	.026	3.64	2.49	4.21	.785	3.032	11.48	3.35	1.105	50	
16	.026	3.50	2.35	3.97	.776	2.997	11.46	3.34	1.114	50	2.48 @ 130°F
17	.026	3.49	2.34	3.95	.774	2.989	11.40	3.33	1.114	50	
18	.026	3.50	2.35	3.97	.774	2.989	11.51	3.36	1.124	50	
19	.025	3.50	2.35	3.97	.775	2.993	11.53	3.36	1.123	50	2.46 @ 130°F
20	----	----	----	----	----	-----	-----	----	-----	--	------------
21	.025	3.42	2.27	3.84	.784	3.028	11.62	3.39	1.119	42	2.6 @ 70°F
22	.025	3.41	2.26	3.82	.785	3.032	11.48	3.35	1.105	50	.748@ -40°F
23	.024	3.38	2.23	3.77	.775	2.993	11.71	3.42	1.143	50	.663@ -40°F
24	.023	3.36	2.27	3.73	.779	3.009	11.70	3.41	1.133	50	2.49 @ 70°F
25	.026	3.68	2.53	4.28	.783	3.024	11.44	3.34	1.104	45	.748@ -40°F
26	.025	3.61	2.46	4.16	.779	3.009	11.47	3.36	1.116	50	.700@ -40°F
27	.026	3.73	2.58	4.36	.770	2.974	11.45	3.34	1.123	50	
28	.026	3.71	2.56	4.33	.777	3.001	11.47	3.35	1.116	50	

TABLE X
GROUP A

1.4 Amp cc @ 70°F

Cell #	Time To 2 V Minutes	Time To 0V Minutes	Time To Deep V Reversal Minutes	Maximum Temperature °F	Vent	Comments
A-12 Total Hours: 4 Hrs/ 12 Min	101 Min 2.36 AH	112 Min	-4.07V @ 123 Min	234.9 @ 124 Min	No	No Buldge
A-16 Total Hours: 4 Hrs/ 12 Min	101 Min 2.36 AH	110 Min	-7.159 @ 121 Min	246.4 @ 126 Min	No	No Buldge
A-17 Total Hours: 3 Hrs/ 42 Min	102 Min 2.38 AH	114 Min	-3.689 @ 125 Min	242.1 @ 131 Min	No	No Buldge
A-26 Total Hours: 3 Hrs/ 42 Min	109 Min 2.54 AH	113 Min	-10.113 @ 127 Min	233.3 @ 127 Min	No	No Buldge
A-27 Total Hours: 3 Hrs/ 36 Min	108 Min	113 Min	-3.591 @ 119 Min	209.1 @ 131 Min	No	No Buldge

TABLE XI
GROUP B

1.4 Amp CC @ 70°F

Cell #	Time To 2V Minutes	Time To 0V Minutes	Time To Deep V Reversal Minutes	Max. Temp. Of	Vent	Comments
B-1 Total Hours:	106 Min 2.47 AH	110 Min	-7.277 @ 115 Min	254.9 @ 122 Min	No	No Buldge
B-4 Total Hours:	106 Min 2.47 AH	111 Min	-7.159 @ 116 Min	259.1 @ 125 Min	No	About to vent slight bulge
B-17 3 Hrs/ 47 Min	105 Min 2.45 AH	109 Min	-3.424 @ 113 Min	221.2 @ 131 Min	No	No Buldge
B-27 3 Hrs/ 47 Min	103 Min 2.40 AH	105 Min	-11.696 @ 114 Min	232.4 @ 115 Min	No	No Buldge
B-18 3 Hrs/ 36 Min	106 Min 2.47 AH	109 Min	-7.380 @ 116 Min	266.6 @ 126 Min	No	Slight Buldge

BA-5557( )/U

DISCHARGE PROFILE

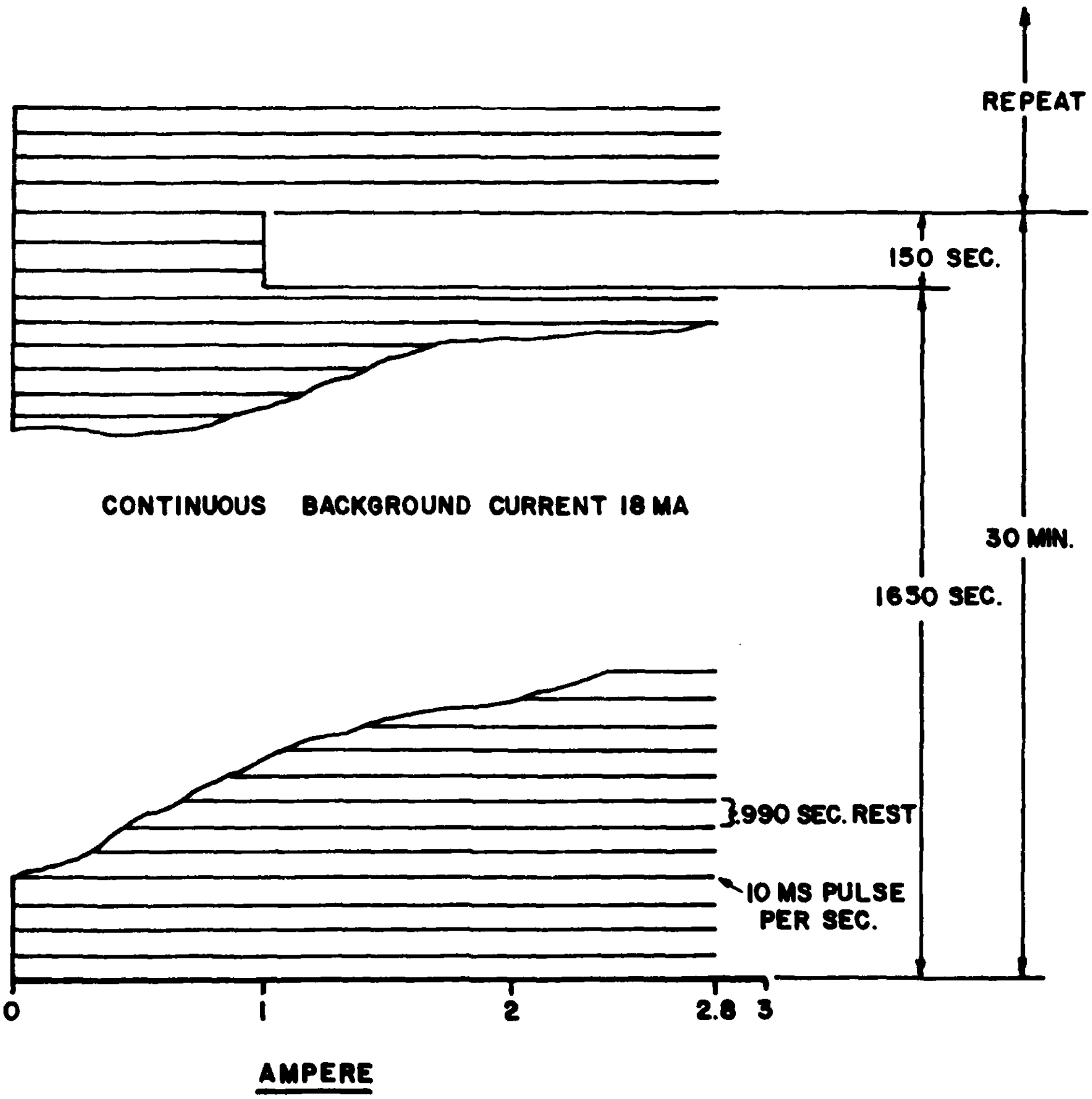


FIG. 1

LITHIUM ORGANIC ELECTROLYTE CELL
LO42 SXH FOR BA-5557( )/U

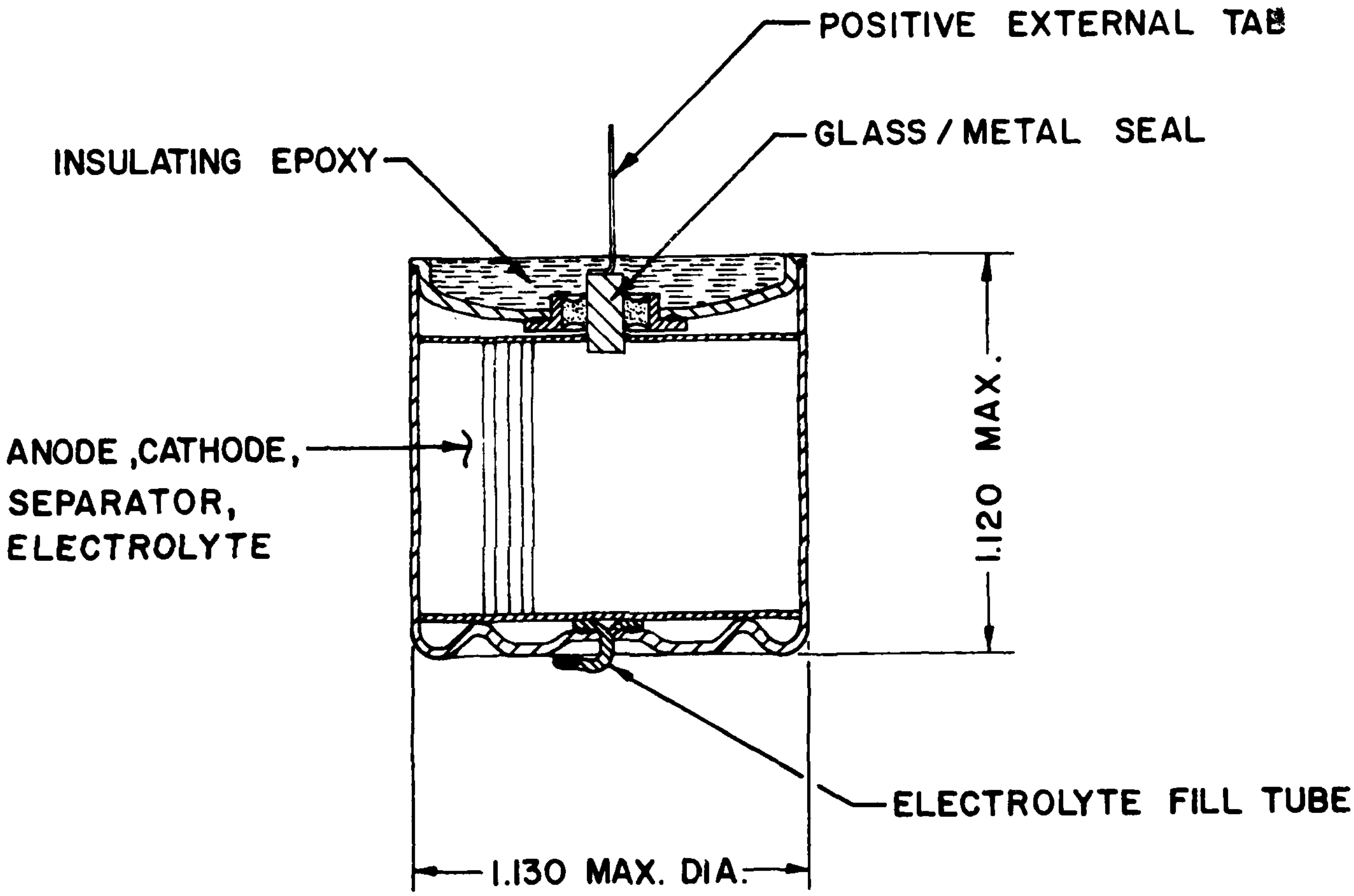
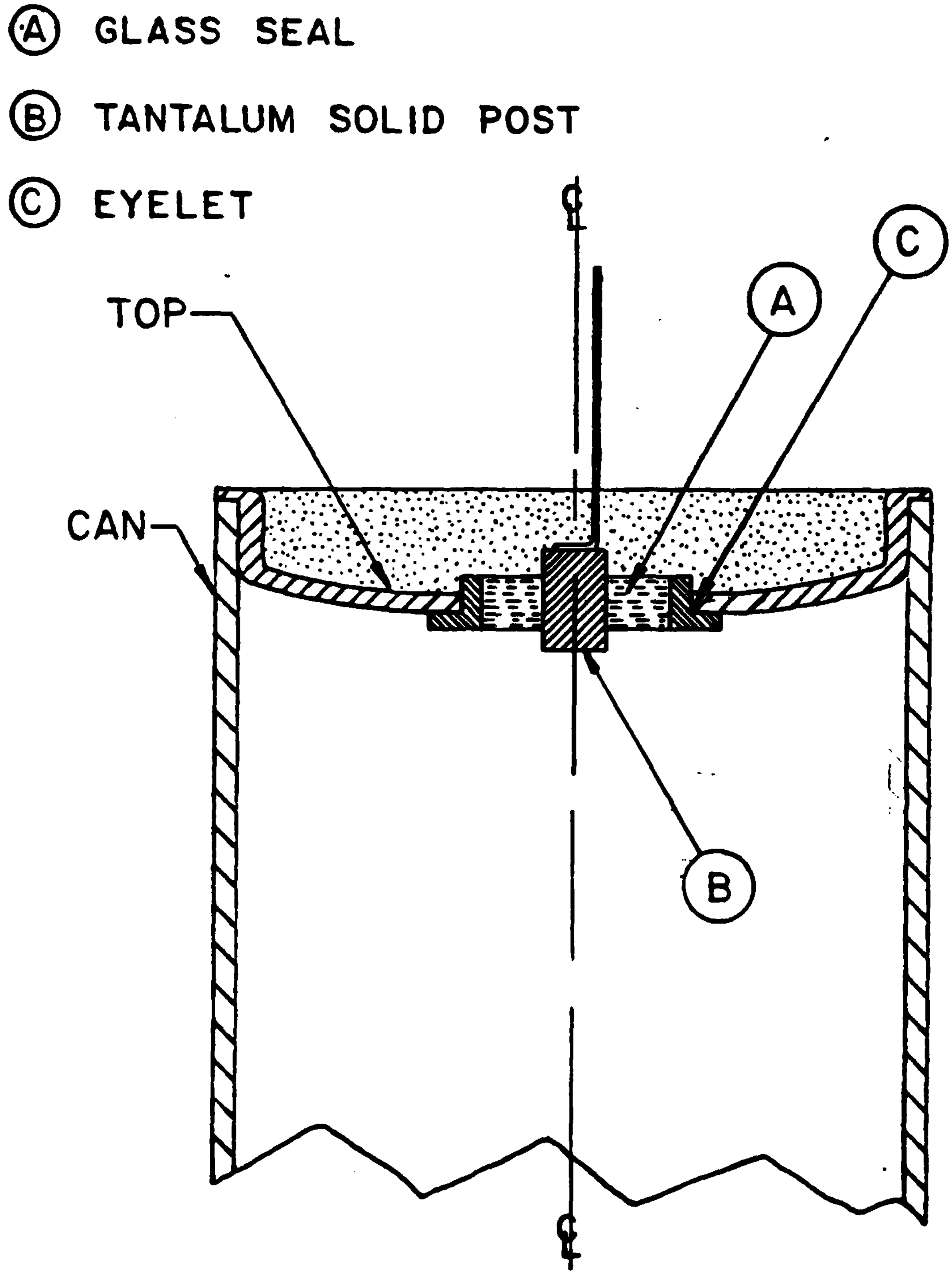


FIG. 2



TOP ASSEMBLY

FIG. 3

3-28-80 J.A.A.

BASE OF CAN WITH CONVOLUTION VENT

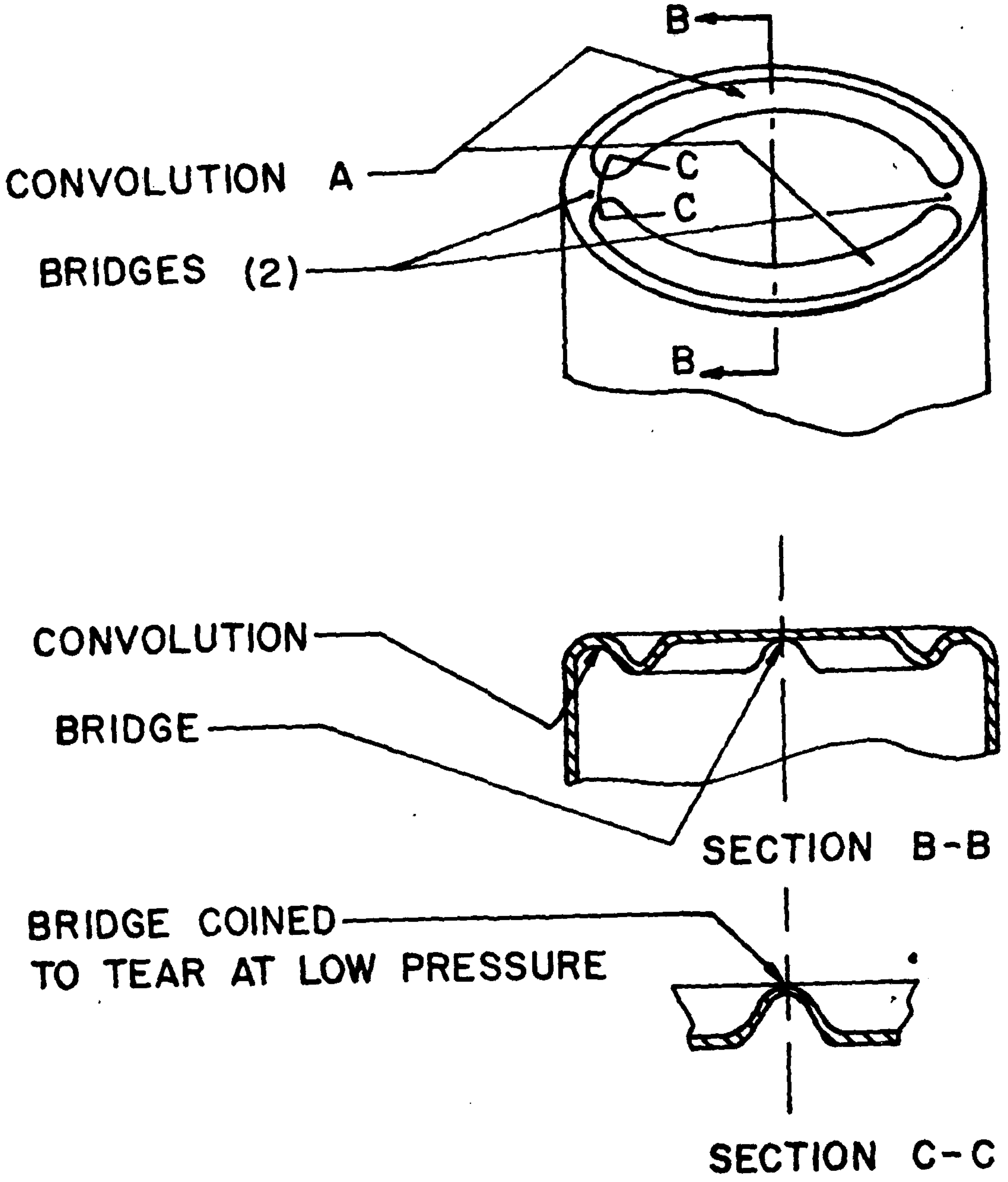


FIG. 4

8-25-80 LAN

PULSE LOAD DISCHARGE AT 70°F.

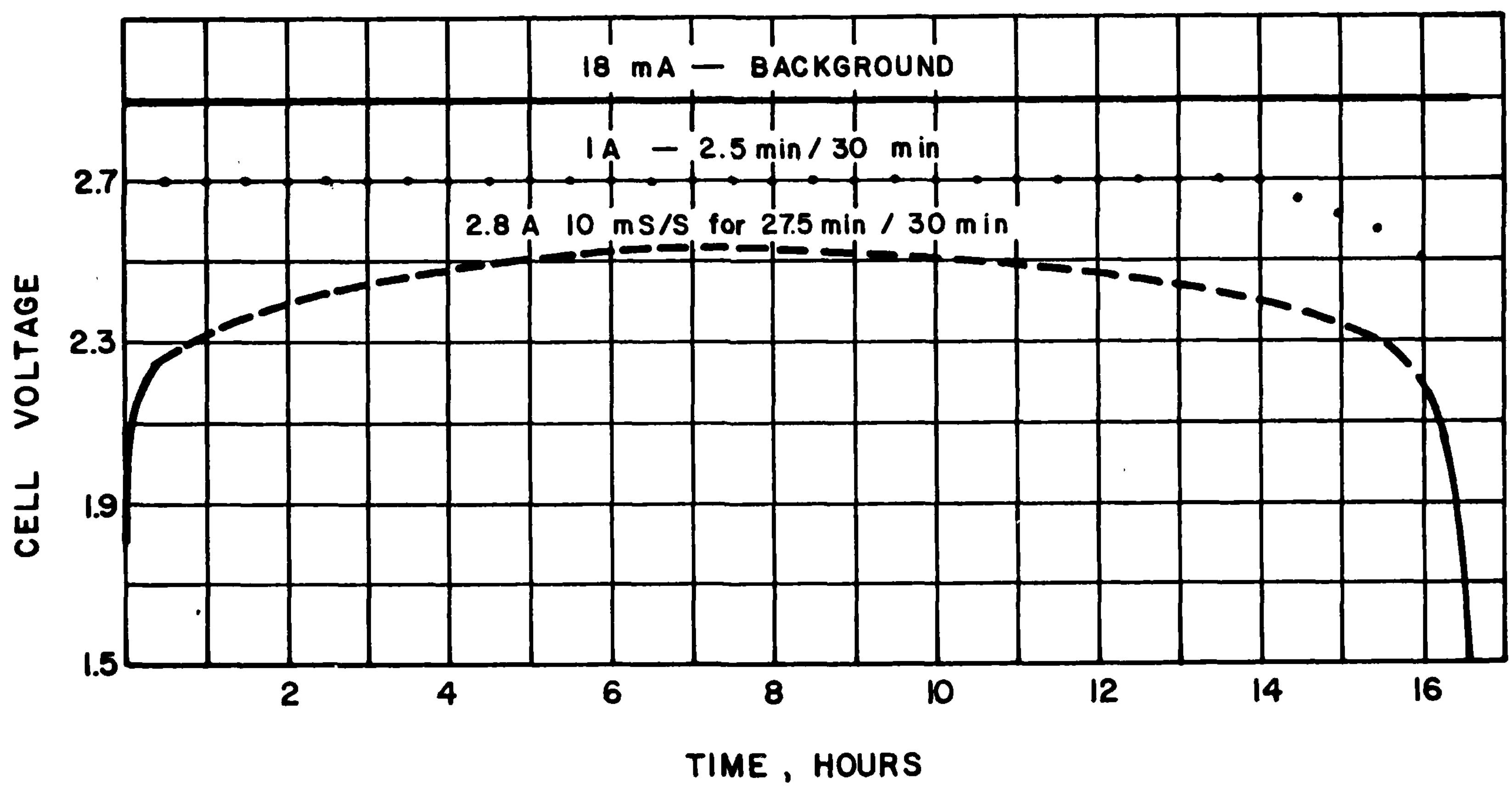


FIG. 5

8-28-80

PULSE LOAD DISCHARGE AT 130° F

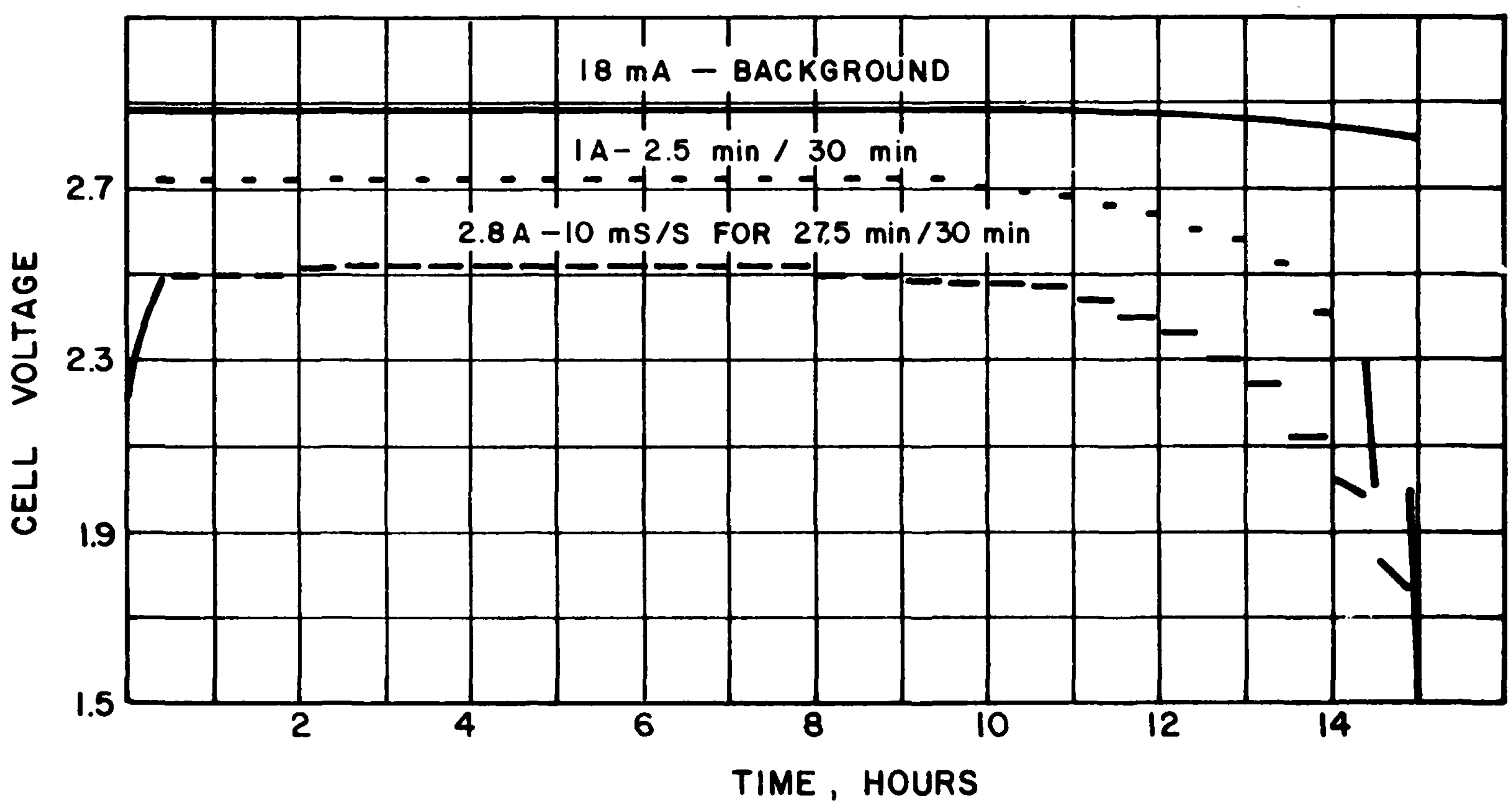


FIG. 6

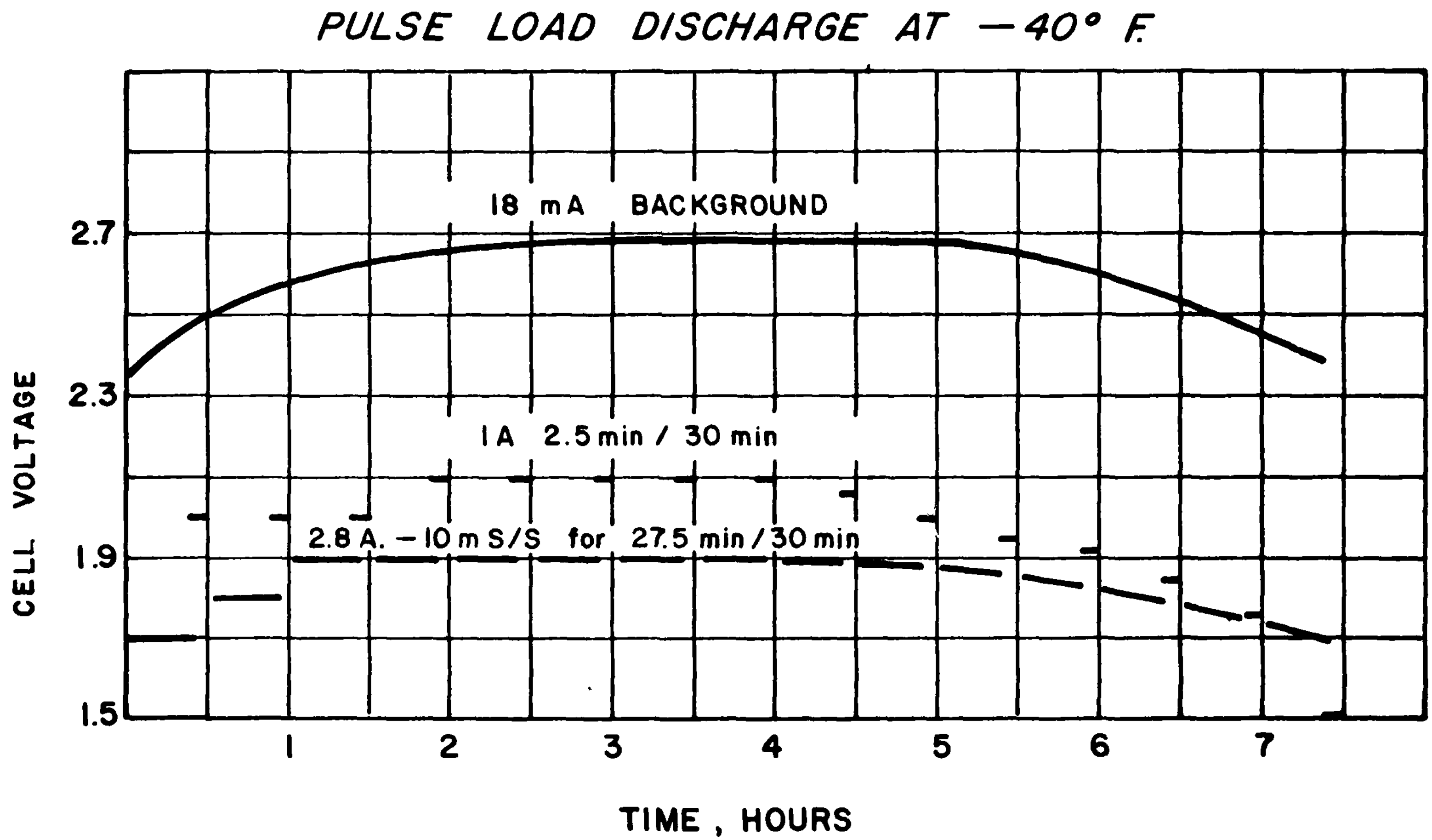

PULSE LOAD DISCHARGE AT —40° F.
18 mA BACKGROUND
1 A 2.5 min / 30 min
2.8 A. — 10 m S/S for 27.5 min / 30 min
CELL VOLTAGE
2.7
2.3
1.9
1.5
1
2
3
4
5
6
7
TIME , HOURS

FIG. 7

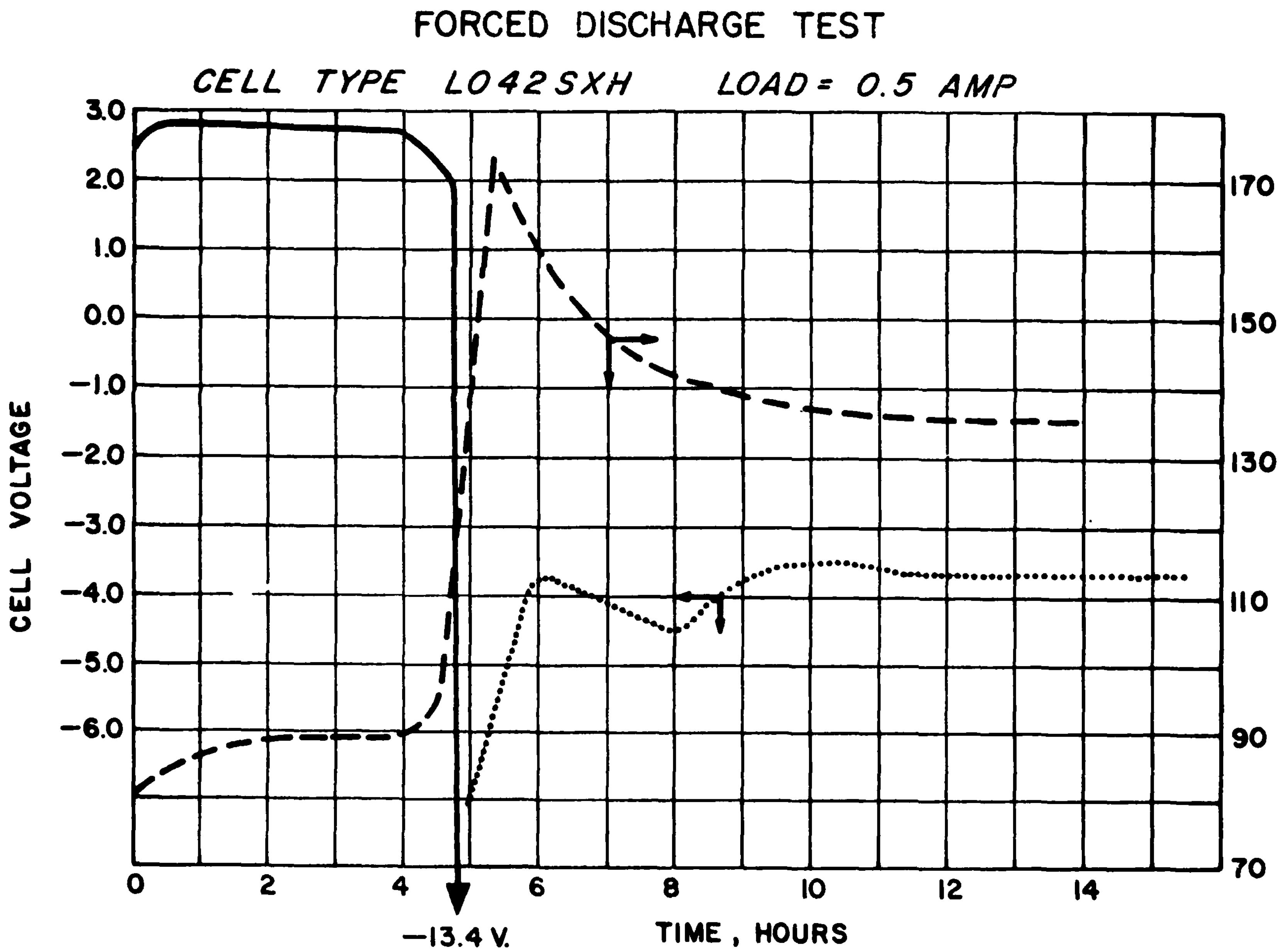

FORCED DISCHARGE TEST
CELL TYPE LO42SXH LOAD = 0.5 AMP
CELL VOLTAGE
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
CELL TEMP., °F
170
150
130
110
90
70
0
2
4
6
8
10
12
14
−13.4 V.
TIME, HOURS

FIG. 8

Primary Organic Electrolyte Battery BA-5557( )/U

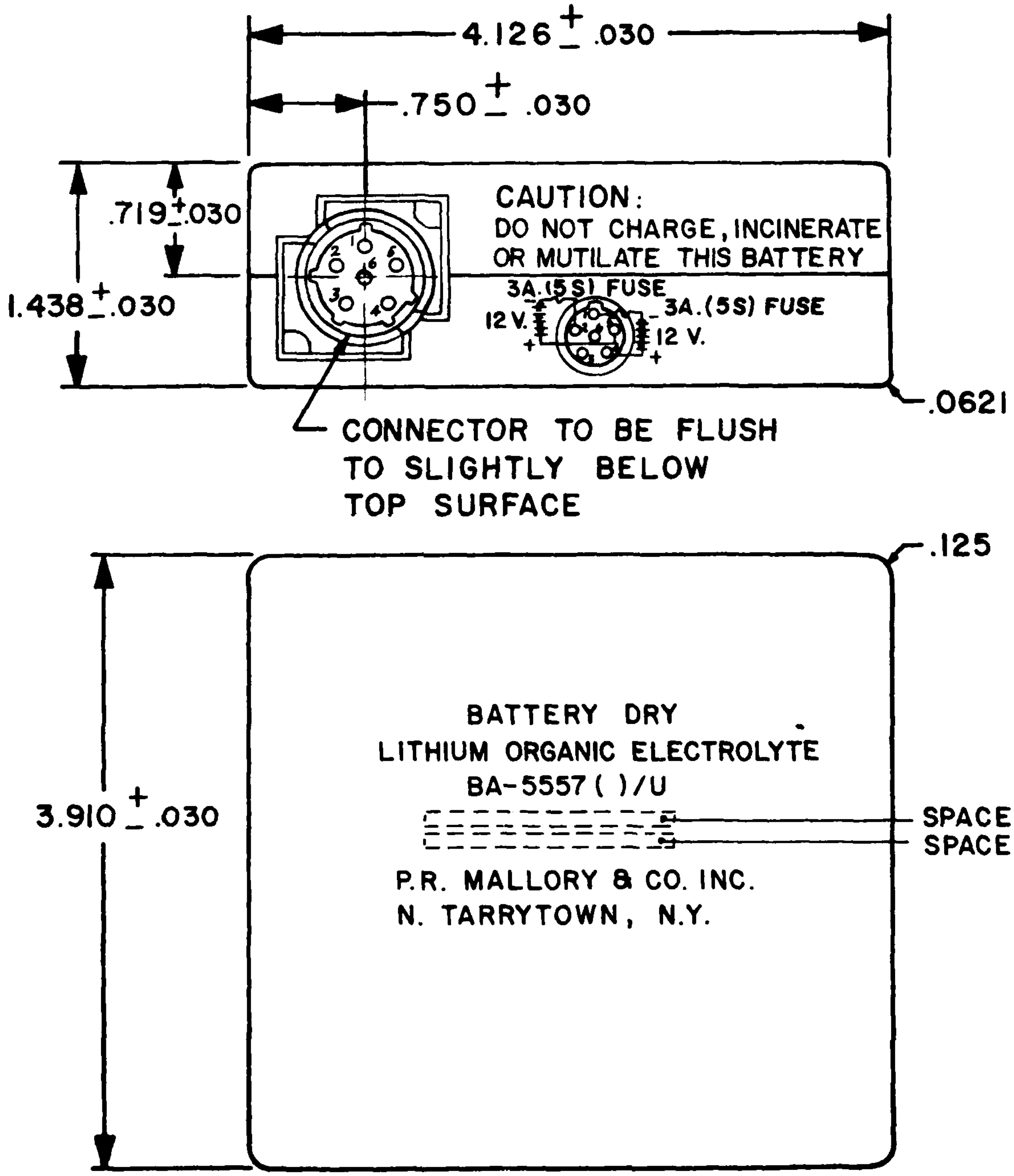


FIG. 9

8-28-80

FORCED DISCHARGED CELL AT 600 MA AT 70°F.

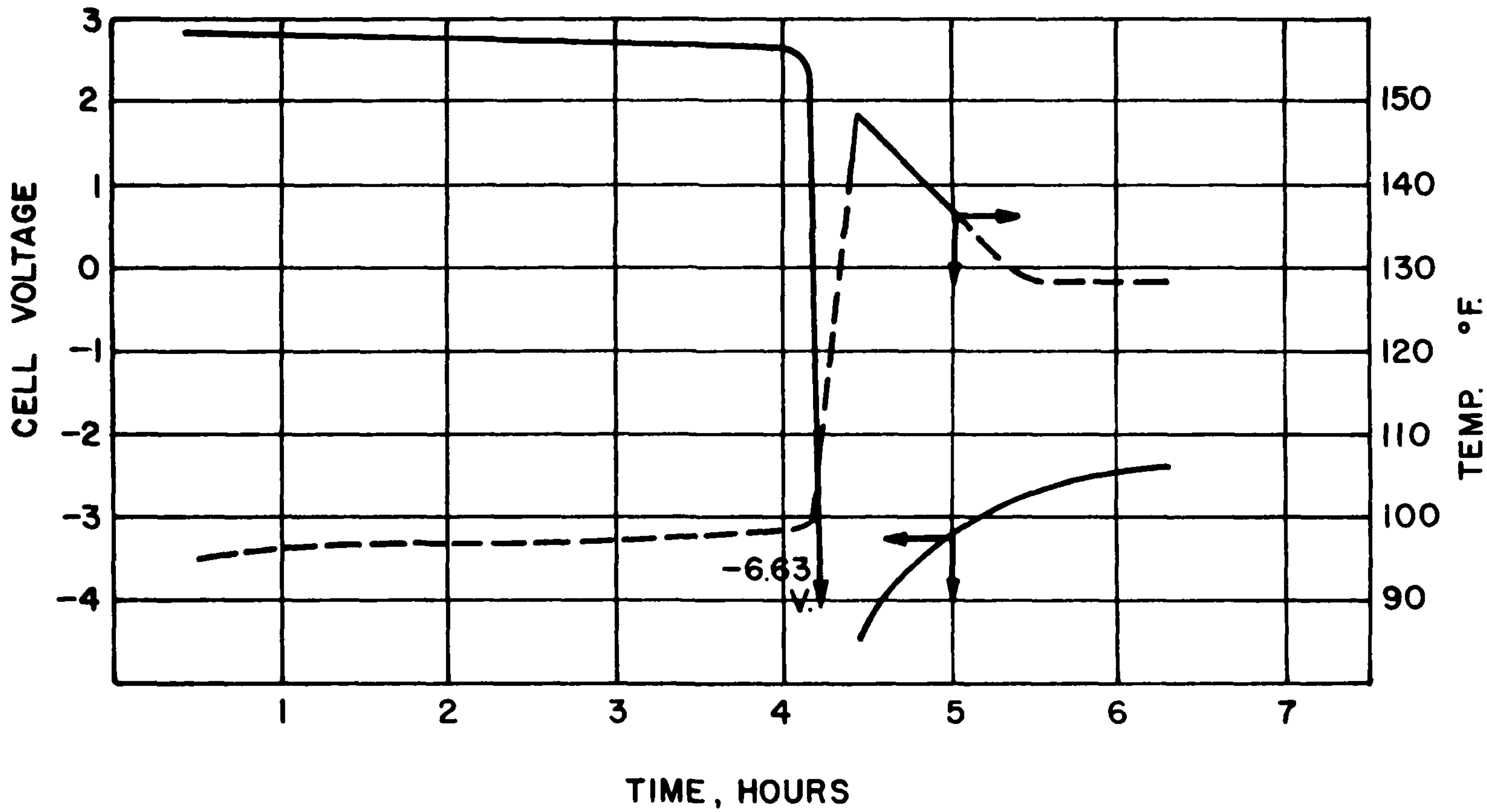


FIG. 10

5.9.80 A.A.A.

FORCED DISCHARGE BATTERY AT 600 MA AT 70°F.

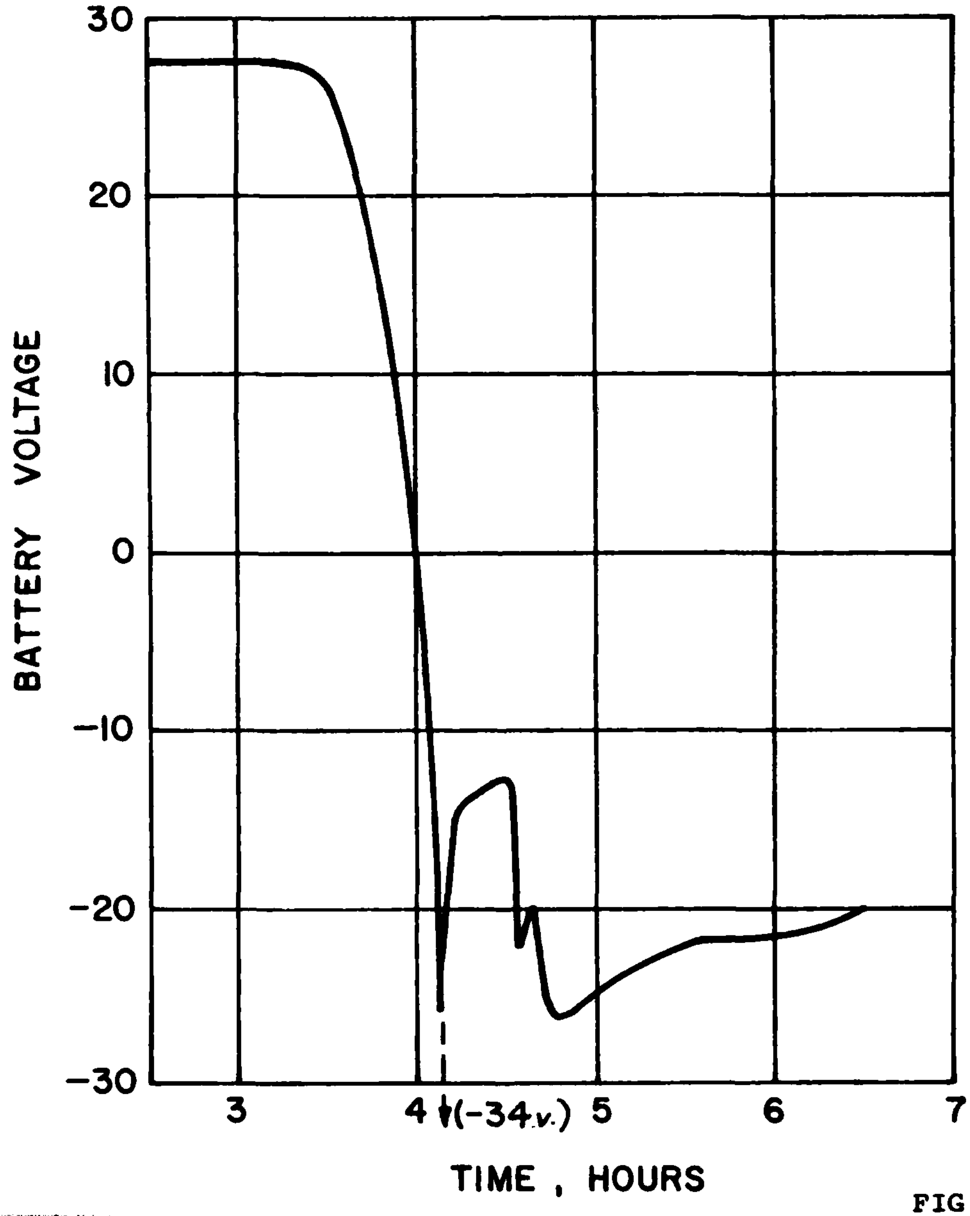


FIG. 11

(36)

LO42SHX

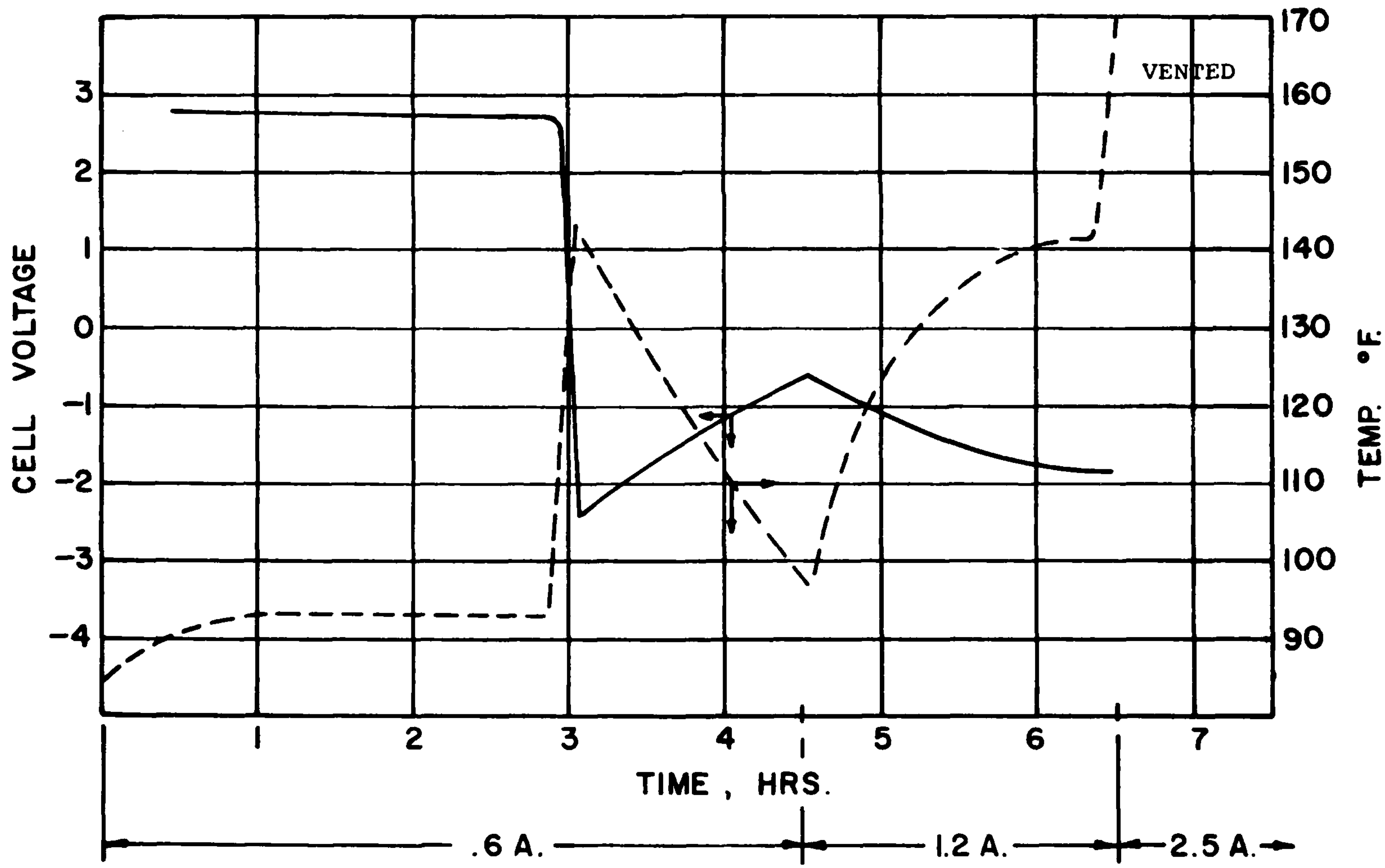


FIG. 12 FORCED DISCHARGE WITH DIFFERENT LOADS

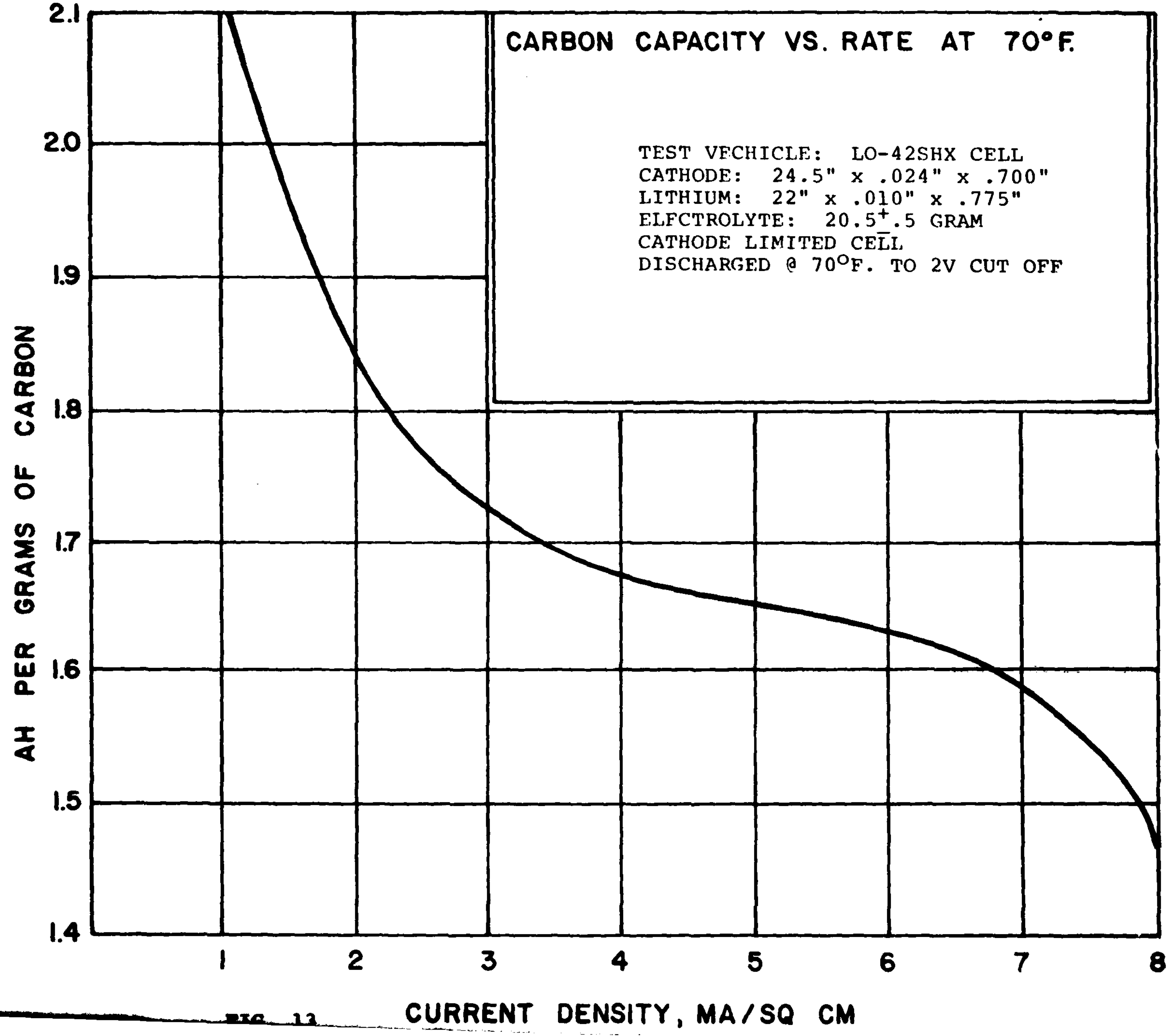

CARBON CAPACITY VS. RATE AT 70°F.
TEST VECHICLE: LO-42SHX CELL
CATHODE: 24.5" x .024" x .700"
LITHIUM: 22" x .010" x .775"
ELECTROLYTE: 20.5±.5 GRAM
CATHODE LIMITED CELL
DISCHARGED @ 70°F. TO 2V CUT OFF
AH PER GRAMS OF CARBON
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1
2
3
4
5
6
7
8
CURRENT DENSITY, MA/SQ CM

FIG. 13

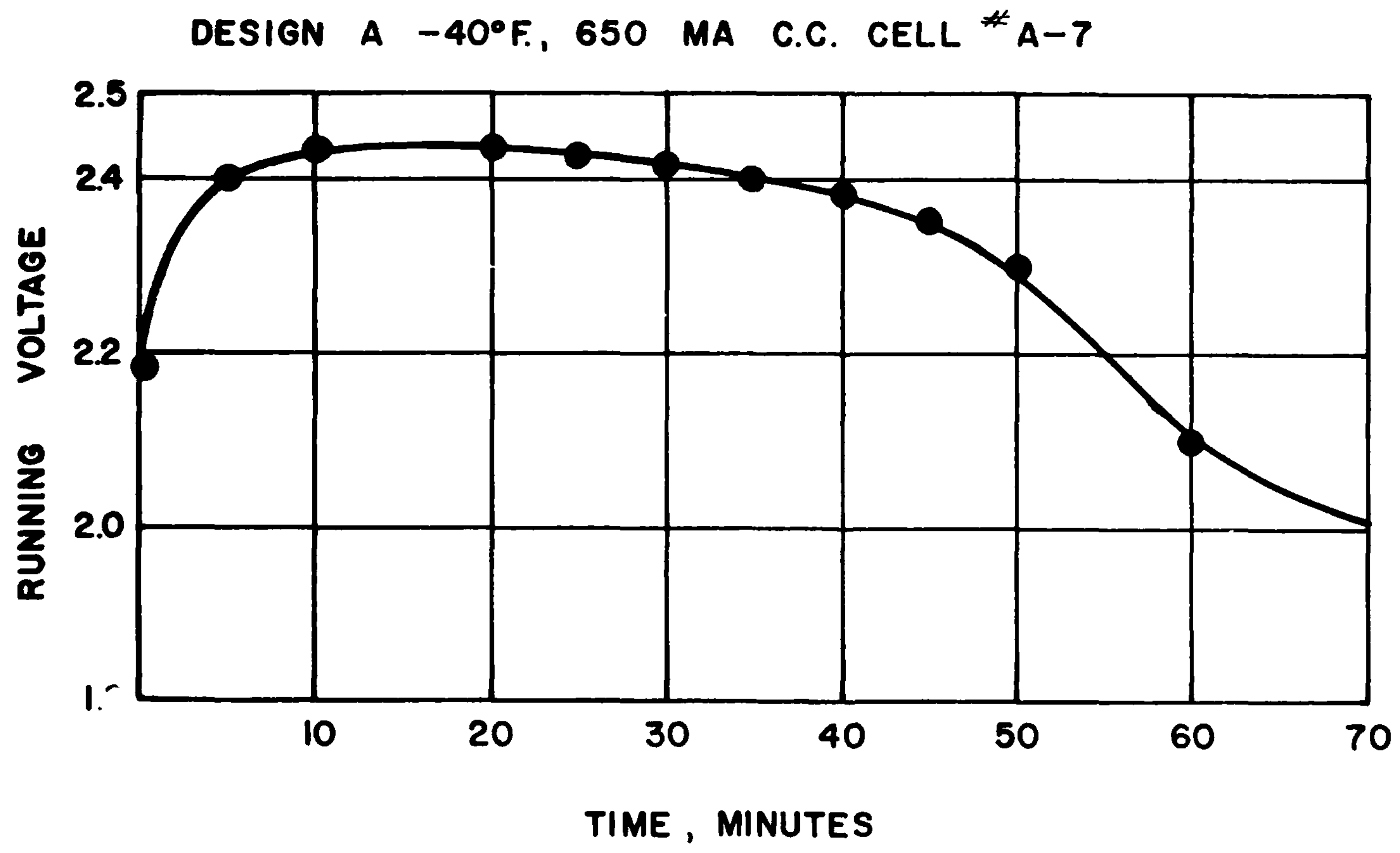
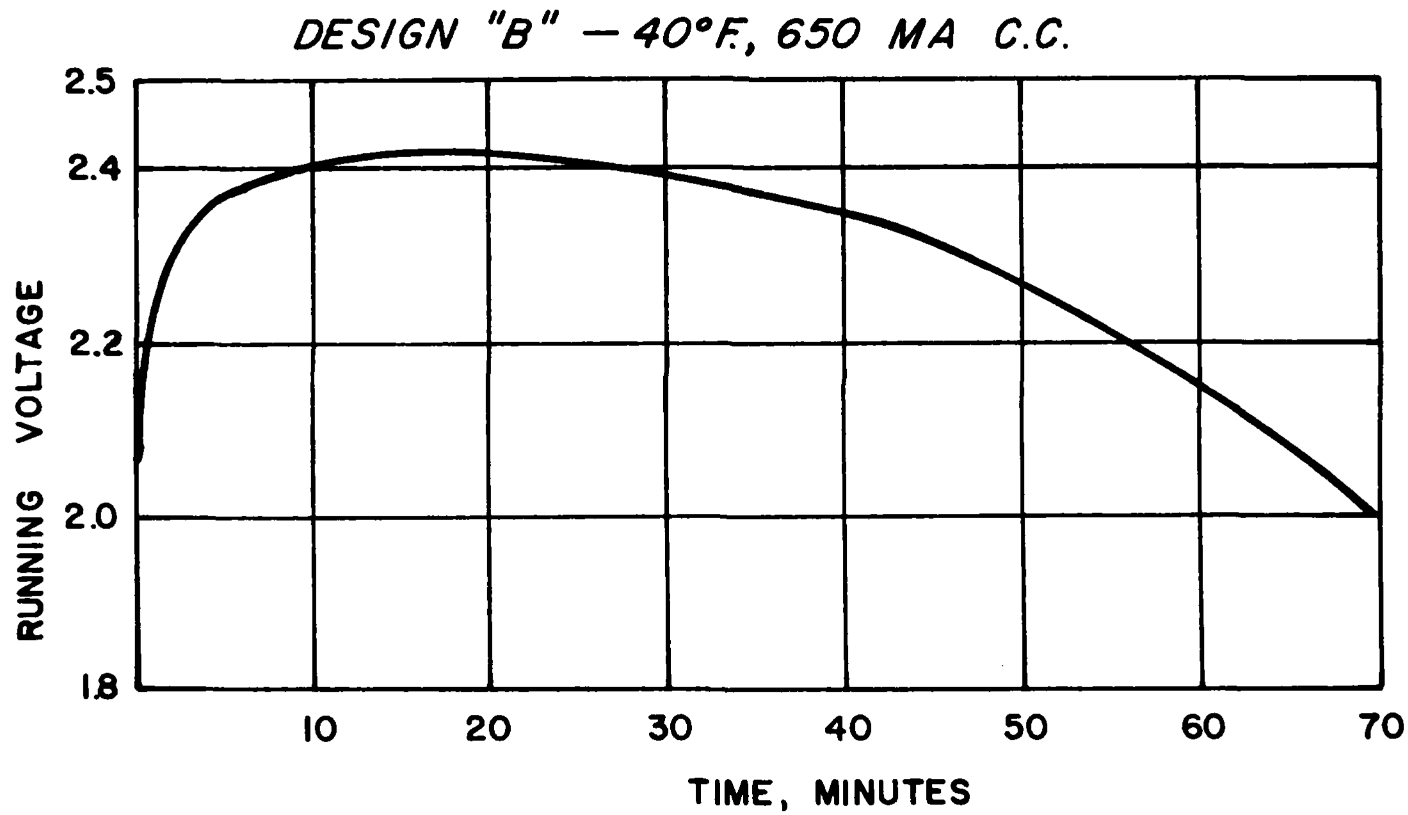


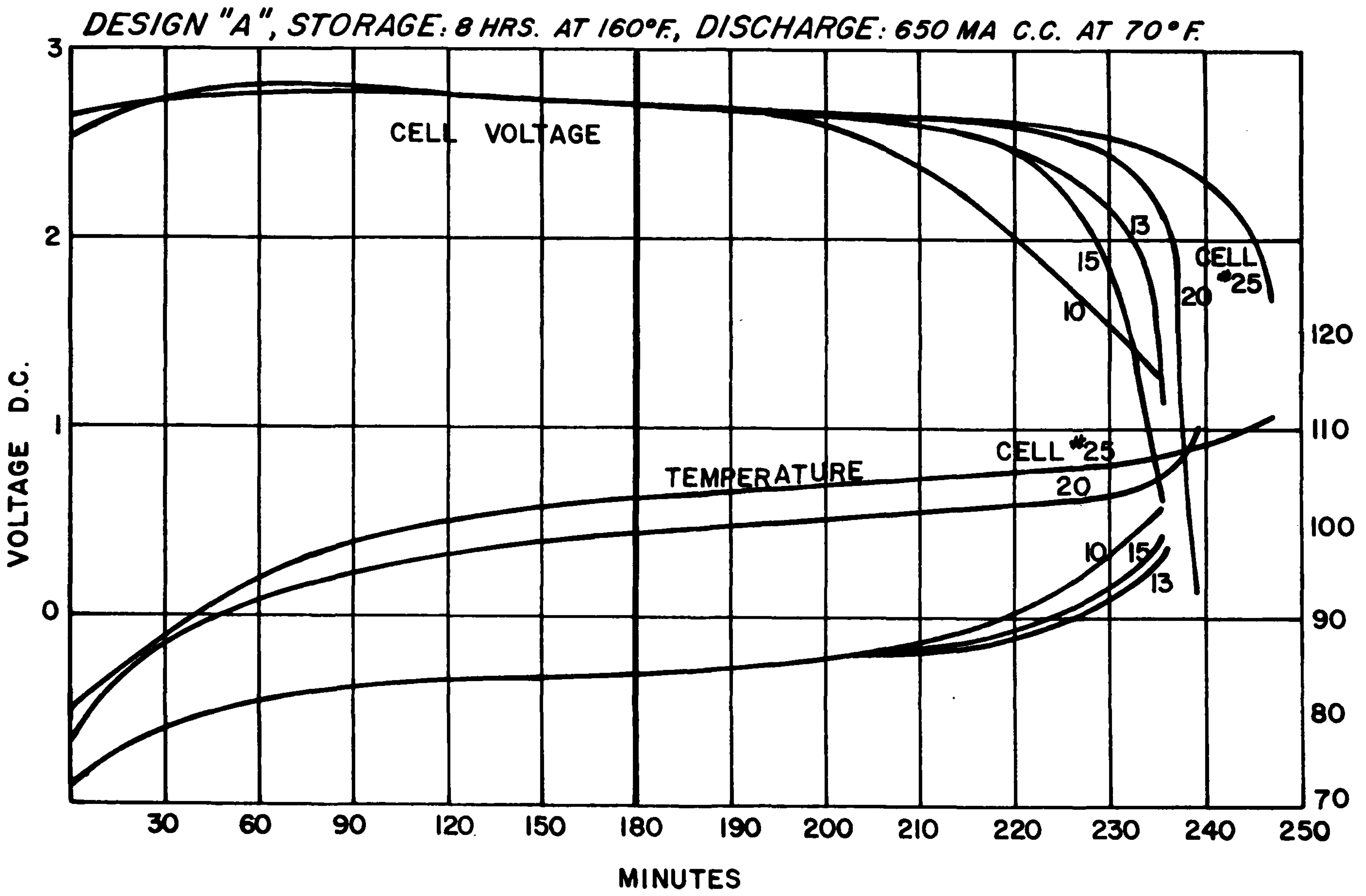
FIG. 14

5·9·80 J.H.A.



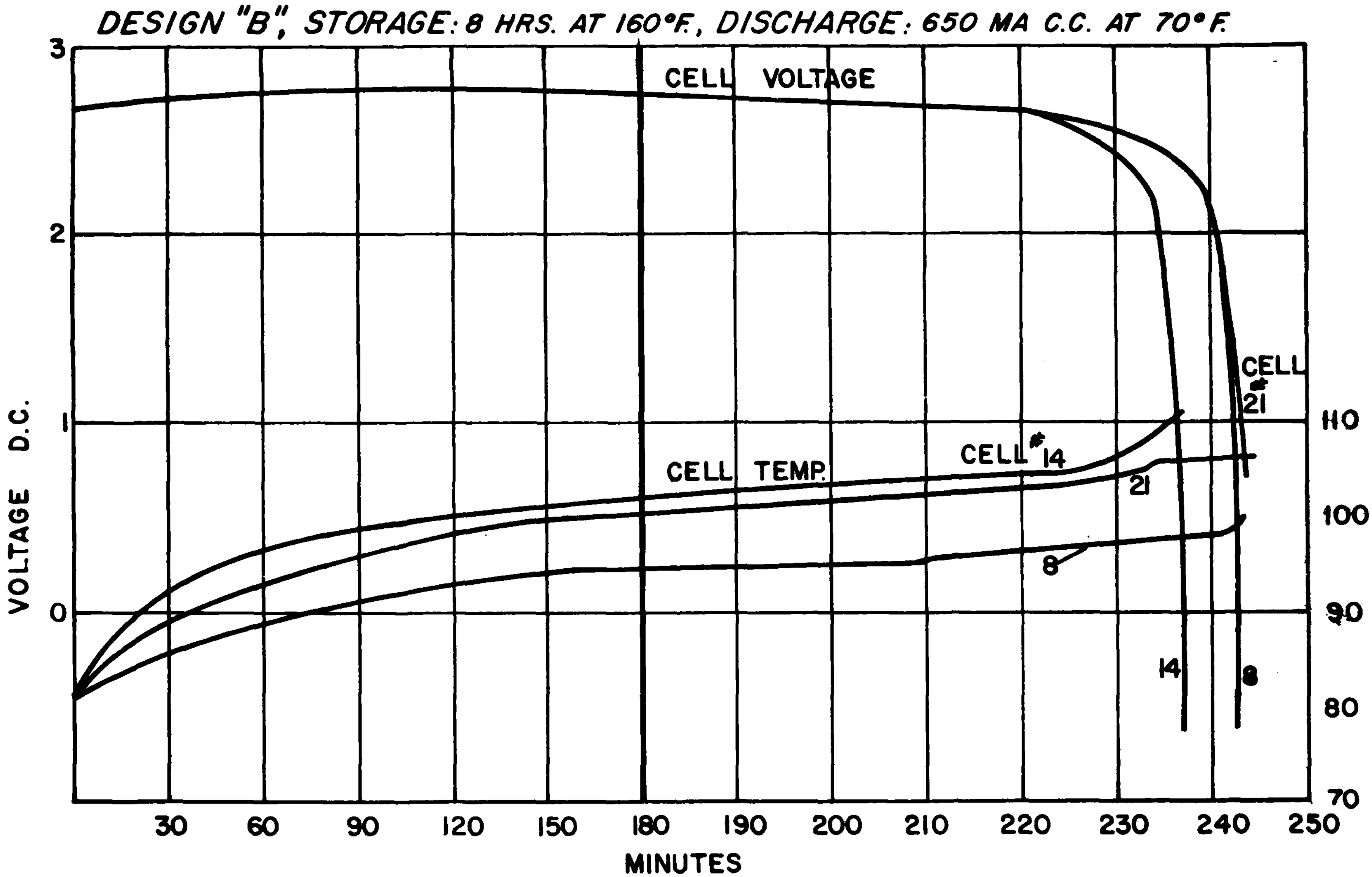
DESIGN "B" — 40°F., 650 MA C.C.
RUNNING VOLTAGE
2.5
2.4
2.2
2.0
1.8
10
20
30
40
50
60
70
TIME, MINUTES

FIG. 15



DESIGN "A", STORAGE: 8 HRS. AT 160°F., DISCHARGE: 650 MA C.C. AT 70°F.
VOLTAGE D.C.
3
2
1
0
CELL VOLTAGE
13
15
10
20
CELL #25
TEMPERATURE
CELL #25
20
10
15
13
TEMP. °F.
120
110
100
90
80
70
30
60
90
120
150
180
190
200
210
220
230
240
250
MINUTES

FIG. 16



DESIGN "B", STORAGE: 8 HRS. AT 160°F., DISCHARGE: 650 MA C.C. AT 70°F.
CELL VOLTAGE
CELL TEMP.
CELL # 14
CELL # 21
21
8
14
8
VOLTAGE D.C.
3
2
1
0
110
100
90
80
70
30
60
90
120
150
180
190
200
210
220
230
240
250
MINUTES

FIG. 17

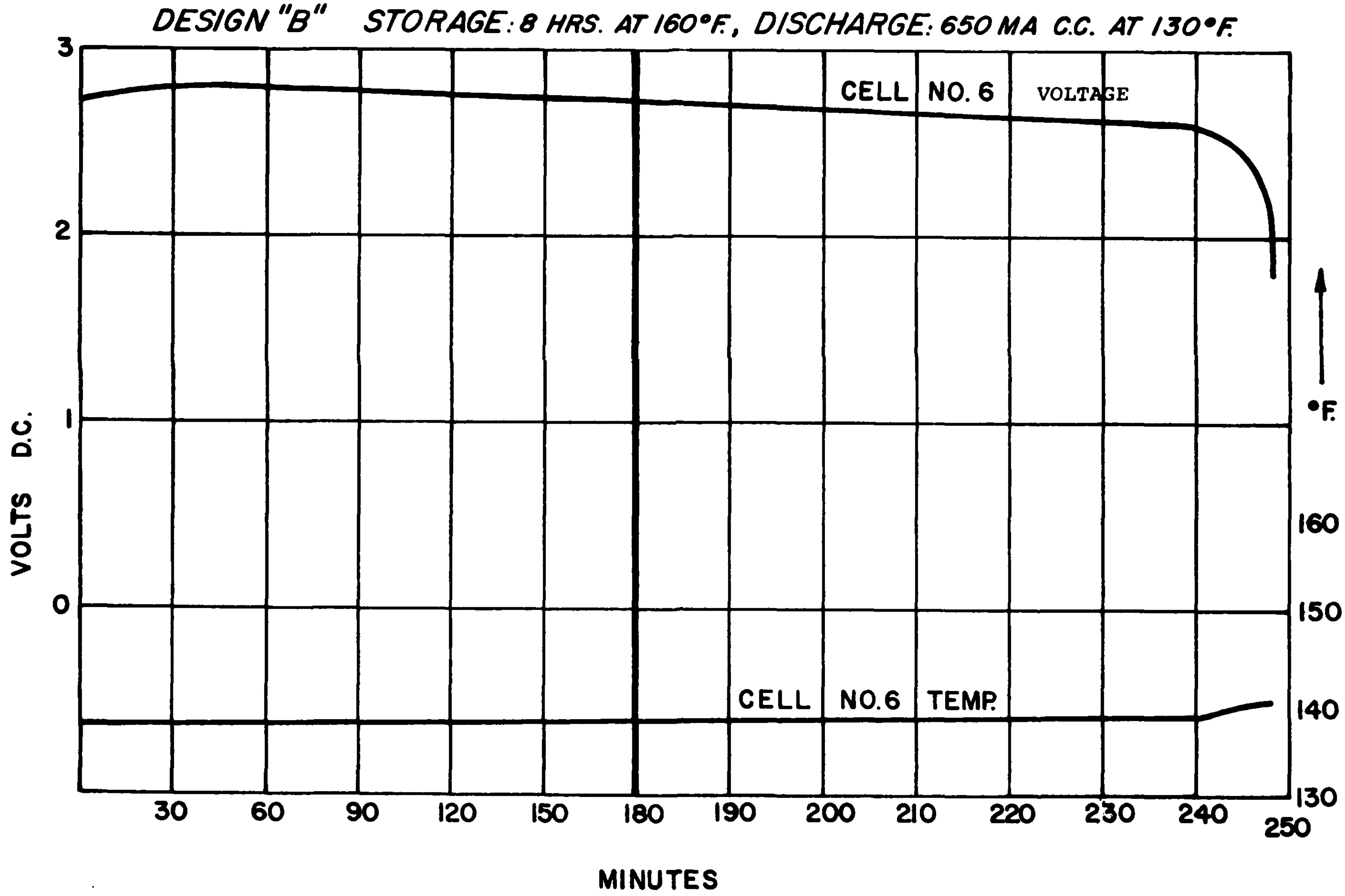
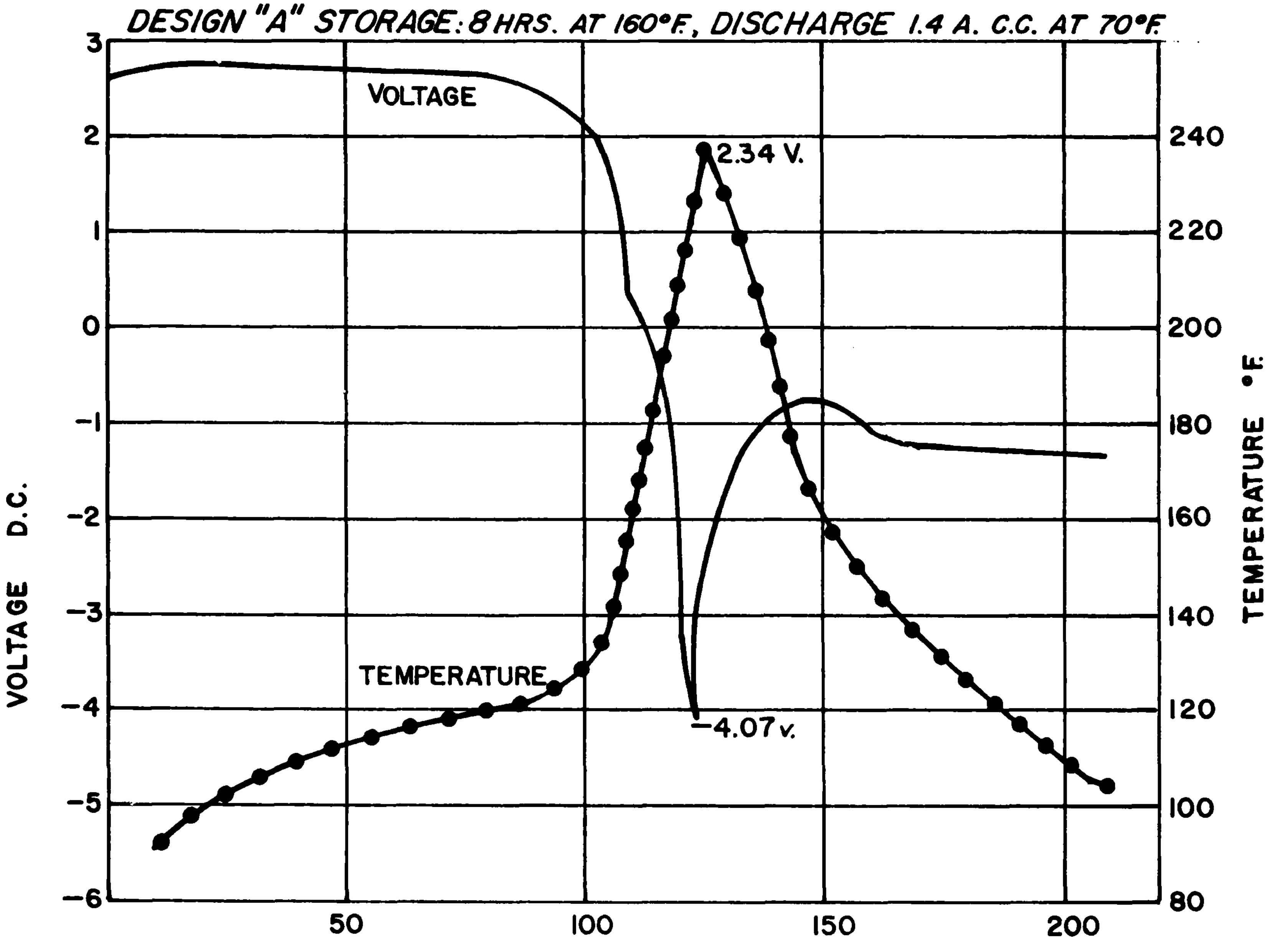
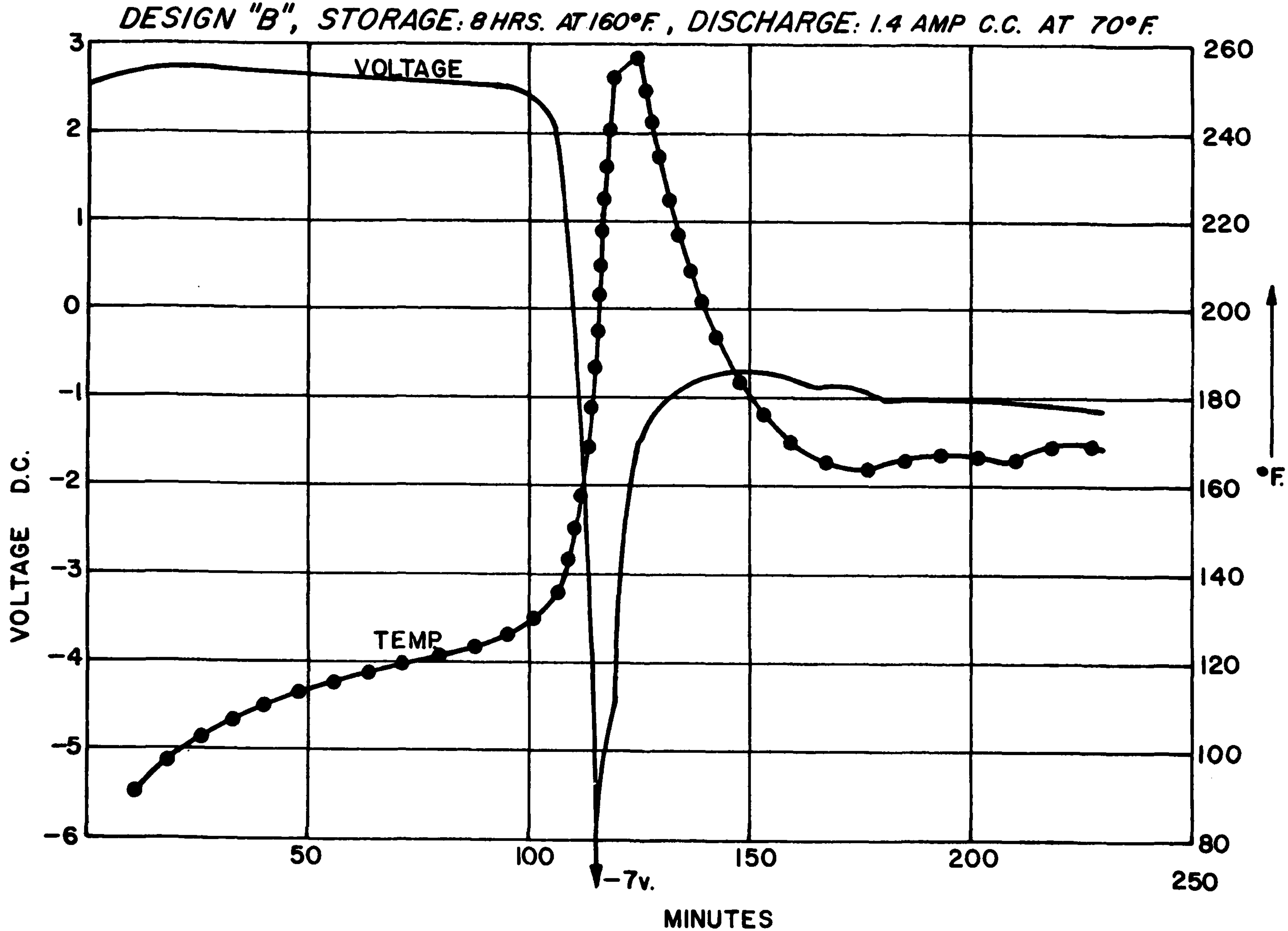

DESIGN "B" STORAGE: 8 HRS. AT 160°F., DISCHARGE: 650 MA C.C. AT 130°F.
CELL NO. 6 VOLTAGE
CELL NO.6 TEMP.
VOLTS D.C.
3
2
1
0
°F.
160
150
140
130
30
60
90
120
150
180
190
200
210
220
230
240
250
MINUTES

FIG. 18



DESIGN "A" STORAGE: 8 HRS. AT 160°F., DISCHARGE 1.4 A. C.C. AT 70°F.
VOLTAGE
TEMPERATURE
2.34 V.
-4.07 v.
VOLTAGE D.C.
TEMPERATURE °F.
MINUTES
3
2
1
0
-1
-2
-3
-4
-5
-6
240
220
200
180
160
140
120
100
80
50
100
150
200

FIG. 19



DESIGN "B", STORAGE: 8 HRS. AT 160°F., DISCHARGE: 1.4 AMP C.C. AT 70°F.
VOLTAGE
TEMP
VOLTAGE D.C.
3
2
1
0
−1
−2
−3
−4
−5
−6
260
240
220
200
180
160
140
120
100
80
°F.
50
100
150
200
250
−7v.
MINUTES

FIG. 20

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